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ABSTRACT

Colleges and universities probably rely on more types of lighting than do other facilities. This booklet is intended to help administrators achieve the goal of lighting energy management--gaining maximum benefit from illumination systems while minimizing energy waste. The development of a lighting energy management plan requires knowledge of the components and systems available, of the existing systems, and of the benefits of lighting. Major lighting concerns and terms are explained and a glossary is provided. The benefits discussed include improved safety and security, increased worker productivity, reduced lighting maintenance expense, and better student achievement. Directions and a form are provided for conducting a lighting energy audit. The final section discusses lighting energy management options (LEMOs) in the areas of lamps, fixtures, ballasts, controls, and maintenance. A hypothetical situation is presented to illustrate a basic method for computing the values of various LEMOs prior to their application. Throughout the booklet a total of nine case histories illustrate various applications of the lighting energy management plan and the associated financial savings. Publications and organizations are listed as sources of assistance. (Author/MLF)

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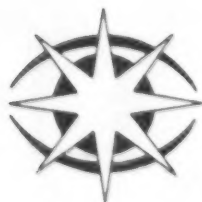
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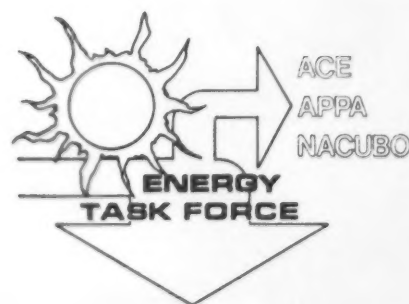
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INTRODUCTION

Colleges and universities probably rely on more types of lighting than any other facilities. Different systems are required for the lighting needs of lecture halls and classrooms, laboratories, computer centers, administrative areas, dormitories, campus walkways, gymnasiums, sports stadiums, parking lots, and many other areas both indoors and outside.

The degree to which colleges and universities depend on lighting can be understood easily, just by imagining what the consequences would be were lighting not available. But the degree to which lighting satisfies the diverse illumination requirements of colleges and universities is not a simple matter of some lighting vs. no lighting. Rather, it depends on the quality of lighting involved. In essence, the better the lighting, the more it is capable of supporting the functions for which it was installed to begin with. Thus, a lighting system that is well designed and properly maintained will do a better job of providing parking lot safety and security than lighting which creates glare or leaves some areas shrouded in darkness.

Although quality of lighting is of paramount importance, it is all too often made secondary to the concern of energy consumption. This is unfortunate, particularly so because high quality illumination and lighting energy conservation are totally compatible; carefully devised modifications can improve both the quality and efficiency of an existing lighting system. To achieve this goal it is essential to understand the difference between *lighting energy conservation* and *lighting energy management*. The goal of lighting energy conservation is reduced lighting energy consumption. By contrast, the goal of lighting energy man-

agement is gaining maximum benefit from illumination systems while minimizing energy waste.

Lighting energy conservation can be characterized as a "narrow focus" approach because it tends to overlook the purpose of lighting and thus the relationships between lighting and other systems. These other systems include the human system which comprises those who use lighting, as well as those who operate and maintain it. Nor does lighting energy conservation necessarily eliminate lighting energy waste, something which occurs whenever an inefficient system is used, or whenever a system does not deliver maximum benefit from the energy it consumes.

Lighting energy management considers lighting interrelationships as well as illumination technology to develop a more sensitive approach to modifications. Thus, in most instances, lighting energy management yields a far better return on capital investment, because it realizes benefits which have a "bottom line" value far in excess of energy savings alone.

Achieving effective lighting energy management requires careful planning, so that each intended action can be analyzed closely before it is put into effect. Development of a lighting energy management plan therefore requires three types of knowledge.

The first type relates to lighting systems and their components. Those recommending modifications must have an intimate understanding of the products available, how they can be applied, how much they will cost, and how much they will save. It is doubtful that any one member of an engineering staff will have this knowledge. Therefore, it generally is advisable to rely on

competent sources of outside assistance.

The second type of knowledge relates to the benefits of lighting, that is, lighting's impact on factors such as safety and security, student comprehension, and worker productivity, among others. The benefits of lighting are discussed in this publication at some length to help assure that all those involved with development of a lighting energy management plan give them appropriate consideration before decisions are made.

The third type of knowledge relates to an awareness of the existing lighting systems, that is, the types of lamps (light bulbs and tubes), luminaires (fixtures), and controls now installed; the degree to which they satisfy needs; the quality of maintenance being performed; the amount of energy being consumed, and so on. This type of knowledge can be gained through conducting a lighting energy audit. When the audit is conducted by a knowledgeable individual, lighting energy management options (LEMOs) can be identified at the same time.

Of course, more than knowledge is needed to make a lighting energy management plan effective. Cooperation also is required. Those making recommendations need the support of those who operate and maintain the lighting, those who use it, and those who will be approving requests for investments in improvements. This support will be forthcoming when those from whom it is requested have knowledge which broadens their perspectives. Thus, it is recommended that this publication be read by all concerned, so that each can have a better understanding of the way in which lighting affects the entire college and university community.

THE BENEFITS OF LIGHTING

College and university officials who have been involved in energy management programs are aware of benefit-cost analysis. When lighting is involved, however, many of the benefits are not accounted for. In fact, the only benefits usually identified are those associated with energy and maintenance cost savings. While these economies can be considerable, many other benefits require consideration. In many cases the value of these other benefits can greatly exceed the value of energy and maintenance cost avoidance. While it is difficult to definitively project the degree to which improved lighting will provide benefits such as enhanced safety and security or increased worker productivity, reasonable estimates can be made by comparing the output of the existing system to that to be derived through modification. The importance of including the value of these benefits in cost-benefit analysis cannot be stressed too strongly or too frequently.

IMPROVED SAFETY AND SECURITY

Campus crime is a growing phenomenon. Numerous studies and case histories show that effective lighting is a deterrent to

such crime—and the lawsuits which often follow—because it causes vandals and felons to move elsewhere to find the darkness they need. Better lighting also permits more effective identification of persons, and provides demonstrable evidence to a campus community that administration is concerned, thereby encouraging widespread involvement in anti-crime efforts.

Indoors, lighting is needed in seldom-used areas as well as in hallways and corridors. Lighting is also needed for safety purposes in stairwells, and wherever people may be exposed to moving machinery, sharp objects, chemicals, and tripping or slipping hazards.

Outdoors, safety and security lighting can be combined with lighting used to provide enhanced aesthetics and better identification. As such, the lighting used to illuminate a statue or building facade is applied for reasons that go far beyond campus pride.

INCREASED WORKER PRODUCTIVITY

Worker productivity is an important concern, particularly in administrative

areas. It is for this reason that many different types of automated or semi-automated office products have gained such popularity. The value of the time they save justifies the expense involved.

Although lighting's impact on worker productivity has been documented through some three decades of research, the value of the benefits involved seldom are considered in evaluating the economic potential of different lighting energy management options (LEMOs).

Research shows that *maximum worker productivity cannot be attained unless the quality and quantity of lighting provided is optimal for the tasks and workers involved.*

Figure 1 illustrates results of a productivity research project. As can be seen, test subjects' productivity is increased and the frequency of their errors is reduced as lighting levels are raised. It is interesting to note that these results apply to younger workers. Generally speaking, older workers need more and better quality light to produce at a rate equivalent to that of their younger counterparts. This is an important point to consider due to the growing number of older persons who constitute the nation's work force.

READING—TYPING TEST

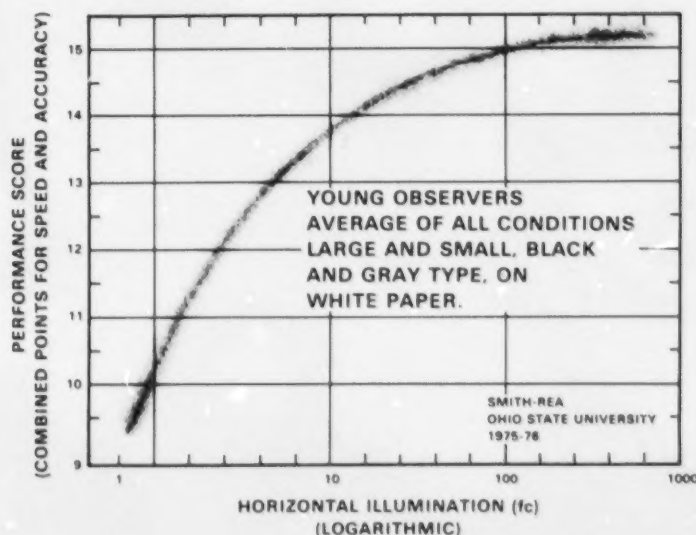


Figure 1 Results of Ohio State University study show that productivity is improved and errors are reduced as lighting levels are increased.

Laboratory test results have been duplicated in many "real world" simulations, such as one conducted by a major insurance company. According to its report, increasing illumination levels from 50 foot-candles (50 fc) to 100 fc cost an additional \$0.35/ft²/yr, but resulted in increased worker output worth \$7.99/ft²/yr. When lighting levels were increased from 50 fc to 150 fc, the additional lighting, which cost \$0.70/ft²/yr, generated increased productivity worth \$22.12/ft²/yr.

The cost of office labor (salaries, wages, fringe benefits, etc.) relates to the cost of lighting system operation as a ratio of approximately 250:1 on a cost/ft² basis. As such, it would be worthwhile to double the amount spent on lighting if the increase results in a productivity improvement of just 0.4%. In most case histories of on-the-job lighting-induced productivity improvements, results were achieved through modifications that actually lowered the cost of lighting system operation, in some instances by as much as 70%.

The problems that can occur when productivity is not considered are illustrated by an incident that occurred when lighting levels in the keypunch area of a Baltimore, Md., Social Security Administration building

were reduced from 100 fc to 50 fc. As shown in Figure 2, worker productivity fell by 28% and was not restored to its former level until the original lighting level also was restored. The value of the productivity loss is unknown. However, if one assumes that the 250:1 relationship existed at the time, every lighting energy dollar saved resulted in a productivity loss worth \$194.

REDUCED LIGHTING MAINTENANCE EXPENSE

The rated lives of some of the newer types of lamps are often far greater than those of the lamps they replace. In addition, because of more light output per lamp, fewer lamps and fixtures typically are required. As a result, there are fewer lamps to replace and maintain, and the frequency of replacement is reduced as well. Techniques such as group relamping can save even more.

LESS DOWNTIME

Very often equipment that has been serviced will go out of service in just a few

weeks. Case histories reveal that better lighting permits a more complete and more accurate inspection of equipment, thus permitting identification of additional items in need of attention. Better lighting also helps reduce the time required to perform services and also helps reduce the number of errors made.

POSITIVE HEAT GAINS

The heat generated by lighting systems reduces requirements otherwise imposed on central or other space heating systems. As such, modifications such as removing lamps and disconnecting fixtures should be looked at closely in terms of the amount of heat lost. Depending on the type of heating system involved, the cost of additional space heating may be more than the value of lighting energy saved. Any such analysis also must consider the fact that lighting imposes a load on the cooling system. Accordingly, changes which increase heating requirements will also reduce cooling requirements. Generally speaking, however, the benefit of lighting heat gains is three times the value of their

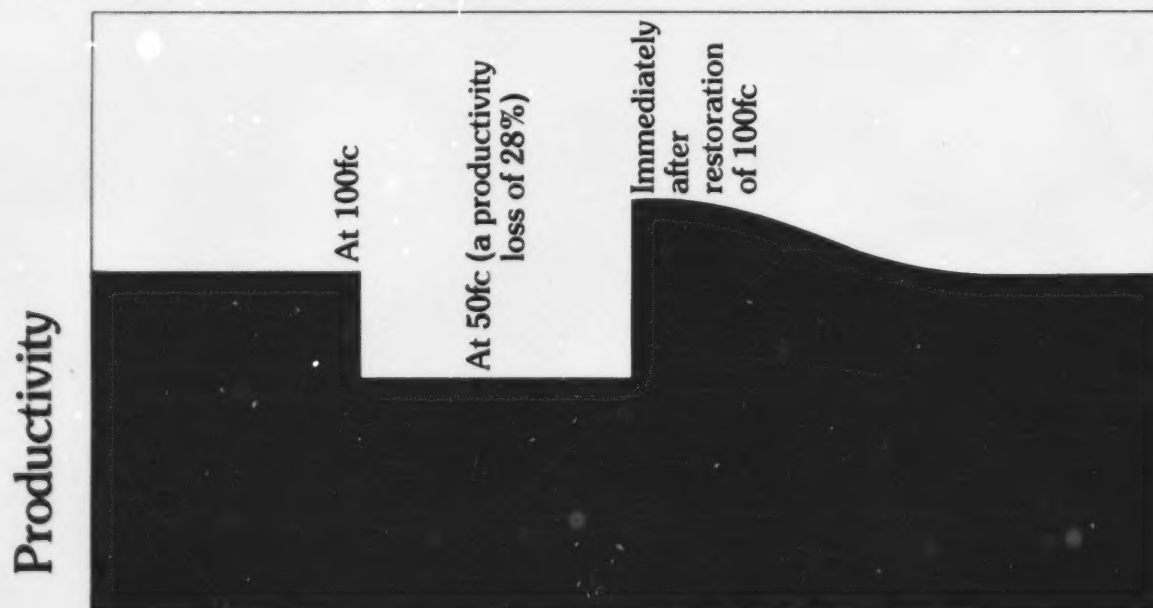


Figure 2: When the illumination level in a Social Security Administration office was reduced from 100 fc to 50 fc, the productivity rate fell by 28%. Productivity jumped when the 100 fc lighting level was restored, then receded with time to the original rate.

detriment. This is not the case in warmer climates, nor does it hold true for the interior zones of larger buildings which often need cooling year-round. In these cases, however, special luminaires are available to remove lighting system heat before it enters a space. They are discussed on page 16.

REDUCED SPACE REQUIREMENTS

Two functions requiring markedly different lighting levels often will be housed in separate spaces. The expense associated with two spaces goes far beyond lighting alone, also involving the cost of constructing the additional space as well as providing it with heating, cooling and ventilation.

The Chesapeake & Potomac Telephone Company in Washington, D.C., demonstrated that effective lighting design can reduce space requirements and attendant cost when just one room was used both as a standard conference area and as a Picturephone[®] television broadcasting studio (Figure 3). The lighting there can be adjusted for the function being conducted through use of in-space controls.

Lighting can be applied in a similar manner on campus to derive greater utility from both indoor and outdoor areas. Thus, a given green space can serve as an evening relaxation/conversation area or, by adjusting controls, as a small field for informal athletic competition.

INCREASED ATTENDANCE AND TICKET SALES

Adding outdoor lighting to a field permits it to be used at night. This not only results in more use of a facility; it also can increase attendance and ticket sales, because very often more people can attend an evening event than a daytime event. For example, after the Niles Township (Ill.) outdoor sports stadium was illuminated, attendance at the first football game of the new season exceeded total attendance for all games of the previous season. In addition, the new lighting provided more security for nighttime joggers, and increased use of the stadium by 150%.

Figure 3: Due to a highly flexible lighting system, this room can serve both as a conference room and a Picturephone[®] television broadcasting studio.



IMPROVED ATHLETIC PERFORMANCE

Optimal athletic performance requires effective lighting, indoors for sports such as basketball, and outdoors, whenever evening play is involved. Unfortunately, many of the lighting systems used for sports stadiums and gymnasiums are obsolete when compared to some of the newer systems now employed. Not only do the newer systems provide more light while consuming less energy, they can also eliminate shadows and glare and better support the needs of television broadcasting.

BETTER STUDENT ACHIEVEMENT

Lighting affects student achievement in a manner similar to that in which it affects productivity. If students have better light to see by, they can perform faster and more accurately.

Tests conducted several years ago reveal another important aspect of the lighting-student achievement relationship. Primary school classrooms were fitted with illumination systems that included fixtures and controls used to highlight visual aids. As a result of highlighting, students' attention spans increased by 39% to 53% in three different experiments. In two of the experiments, where tests were administered, it was found that student achievement increased by as much as 52%.

The system components required to

implement instructor-controlled highlighting can be integrated into the overall lighting system at relatively little expense. The energy consumption involved is minor because the lighting is on for only short periods of time.

MORE EFFECTIVE IDENTIFICATION

Lighting is used for identification, to help those who may not be familiar with a campus find their way at night. The most obvious form of identification involves illumination of signs. Other forms include the illumination of building facades and of walkways leading to different buildings or areas. The lighting used for purposes of identification also can help enhance aesthetics and improve safety and security.

ENHANCED AESTHETICS

Lighting can be used indoors to enhance the appearance of virtually any space, be it a dining hall or a museum. The impact of lighting on outdoor aesthetics can be even more pronounced, because lighting at night establishes the environment. Thus, when outdoor lighting is well designed, it can achieve the effect of *environmental integration*, linking different areas of the campus into a handsome, fully-integrated whole. And the same lighting used to enhance outdoor aesthetics can also be used for purposes of safety and security, among others.

INCREASED RETAIL SALES

Many colleges and universities operate stores where books, supplies and other items are sold. Case histories demonstrate that new lighting can increase sales. As an example, the Sloan's supermarket chain in New York City removed two fluorescent lamps from most of its stores' four-lamp fixtures. Management did not like the altered appearance of the stores and therefore restored four lamps to each fixture, relying on reduced-wattage high-efficiency lamps rather than the standard lamps used originally. As an immediate result, sales shot up from 10-15%.

Sales also increase when illumination is used to highlight displays of impulse purchase items or those "on-special." Effective outdoor lighting works to increase retail sales, too. When good safety/security lighting is installed, it helps people overcome their fear of shopping after dark. It can also make a store more noticeable.

CASE HISTORY

Central Michigan University (Mount Pleasant, Michigan) was concerned about nighttime campus safety and security, as well as the cost of the lighting used for that purpose. According to Robert F. Ringel, CMU's Director of Plant Extension, the existing system comprised 384 pole-mounted mercury vapor fixtures and lamps. Of these, 105 were used for roadway lighting (400W lamps mounted on 30-foot poles spaced 200-240 feet apart) with the remaining 279 units being used for walkway lighting. Of the walkway lighting units, 244 illuminated high security areas and used 250W lamps, as did 25 of the remaining 35 in other areas. The other ten relied on 175W lamps, and all 279 were mounted on ten-foot poles spaced randomly.

The input wattage of the fixtures were:

Mercury Vapor Lamp Wattage	Mercury Vapor Fixture Wattage
175W	205W
250W	285W
400W	455W

Overall connected load amounted to 126.49kW. On average, all lighting is activated 4,380 hours per year, resulting in total energy consumption of 554,026 kWh per year. At an average energy rate of \$0.0401 per kWh, the energy consumed by the lighting system cost \$22,216 each year.

Other costs were those for replacement lamps (\$585 per year) and lamp replacement labor (\$455 per year) for a total annual expense of \$23,256.

Mr. Ringel said, "We decided to use high pressure sodium (HPS) lighting with wattages that would greatly increase existing lighting levels, thereby to enhance campus safety and security at night. In so doing, we recognized the relationship between lighting and the function that it was in this case intended to provide. We also considered other systems—namely, security. At the time, we were spending about \$150,000 per year on the security patrols for the areas in question. It was reasoned that, while our proposed strategy would not reap maximum energy savings, it would greatly minimize energy waste, because the HPS lamps are far more efficient. Perhaps more important, it would also help improve safety and security, and thereby permit us to reduce security patrols while providing equal or better protection."

All existing mercury vapor fixtures were converted to HPS operation by replacing existing ballasts with HPS ballasts, using HPS ballast conversion kits.

The 105 roadway lighting fixtures were converted from 400W mercury vapor lamps to 250W HPS lamps. This resulted in a savings of 145W per fixture, despite the fact that the new lamps provide half again as much light (25,000 average lumens for the 250W HPS vs. 16,500 average lumens for the 400W mercury vapor).

"We could have converted the 244 high-security walkway fixtures from 250W mercury vapor operation to 150W HPS, and still have increased light output by almost 30% (13,500 lumens vs. 10,500 lumens) while decreasing energy consumption by one-third (190 input watts vs. 285 input watts). Instead, we decided that 250W HPS lamps would be best, to help assure a high level of safety and security while also permitting reduced security patrols and attendant costs," Mr. Ringel noted. As a result, the amount of light provided by the high-security walkway lighting was more than

doubled (135% increase, 25,000 average lumens per lamp vs. 10,500 per lamp), but we also increased connected load and energy consumption. This is a classic illustration of the difference between energy conservation and energy management. In essence, the increased (and more efficient) use of energy resulted in more money saved rather than less, because the benefits of lighting were considered and so obtained.

The remaining 35 walkway lamps were all converted to 150W HPS.

The cost of the conversion amounted to \$30,000 including the cost of 384 ballast conversion kits (\$17,550), 384 new lamps (\$6,450), and the cost of in-house installation labor (\$6,000).

The new lighting, while providing substantially more illumination than the original system, still consumed 51,027 kWh less each year. As such, the cost of energy consumption fell from \$22,216 per year to \$20,170 per year. The cost of replacement lamps increased from \$585 per year to \$1,185 per year, because the HPS lamps are somewhat more expensive. The annualized cost of lamp replacement labor—\$455 per year—stayed the same.

Altogether, then, the modified system costs \$21,810 per year for operation and maintenance, representing a \$1,446, 6.2% annual savings from former expenses. Given the initial cost of \$30,000, the simple payback on the investment amounted to 20.75 years, and simple return on investment (ROI) amounted to 4.8% per year. However, these figures do not reflect the fact that, after the conversion, the far superior lighting permitted a 7% security patrol reduction, for a savings (lighting benefit) worth about \$10,500 per year. As such, total annual savings amounted to \$1,446 + \$10,500 or \$11,946 per year, for a simple payback of just 2.5 years, and a simple ROI of 39.8%.

MAJOR LIGHTING CONCERNS AND TERMS

In addition to understanding the benefits of lighting, it is important to be familiar with several major lighting concerns and terms that are essential for general comprehension of major issues.

QUALITY VS. QUANTITY

The amount of illumination falling on a task is measured with a lightmeter. Readouts are given in footcandles (fc). The foot-candle is an easily specified, calculated and measured quantity and is the basis for much lighting design. Its utility is limited, however, because it does not consider the quality of illumination and its impact on visual performance.

The quality of illumination generally refers to factors that cannot be readily measured. Rather, they are perceived by the viewer. One of the most important quality factors is visual comfort. Another is contrast rendition. A third is color rendition. And, there are many others.

To derive maximum benefit from a lighting system, quality and quantity must

be kept in balance. Generally speaking, when quality is kept to a maximum, quantity can be kept to a minimum. The additional investment that may be required to design and install a quality system usually will be paid for many times over due to the energy saved and additional benefits derived.

Although quality and quantity of lighting often are addressed as separate concerns, quality actually encompasses quantity. In short, you cannot have a high quality lighting system unless it provides, among other things, the amount of light needed for whatever function is being illuminated.

It is important to recognize that the amount of light in a space may have little bearing upon the amount of light *perceived to exist* by those for whom the illumination is provided. For example, if the lighting system creates unwanted veiling reflections (Figure 4), 100 fc may create visibility equal to 50 fc without veiling reflections. By the same token, a high quality lighting system that registers only 50 fc on a lightmeter may actually provide the visibility one normally associates with 100 fc.

LUMINANCE VS. BRIGHTNESS

The term "luminance" and "brightness" often are used interchangeably, but they differ from a technical standpoint. Luminance is the measurable component of reflected light. The measurement used is the footlambert. "Brightness" refers to the physical reaction to luminance, and thus considers both the amount of luminance involved and the condition of the eyes affected by it. "Photometric brightness" is another term used to define luminance, meaning brightness that is measurable with a photometer, independent of eye conditions.

Luminance creates the contrast needed to see. The printing on this page reflects light differently from the page itself. This difference is the contrast.

Contrast obviously is highly desirable for all seeing tasks. However, marked contrasts in the general field of view can cause discomfort or even disability.

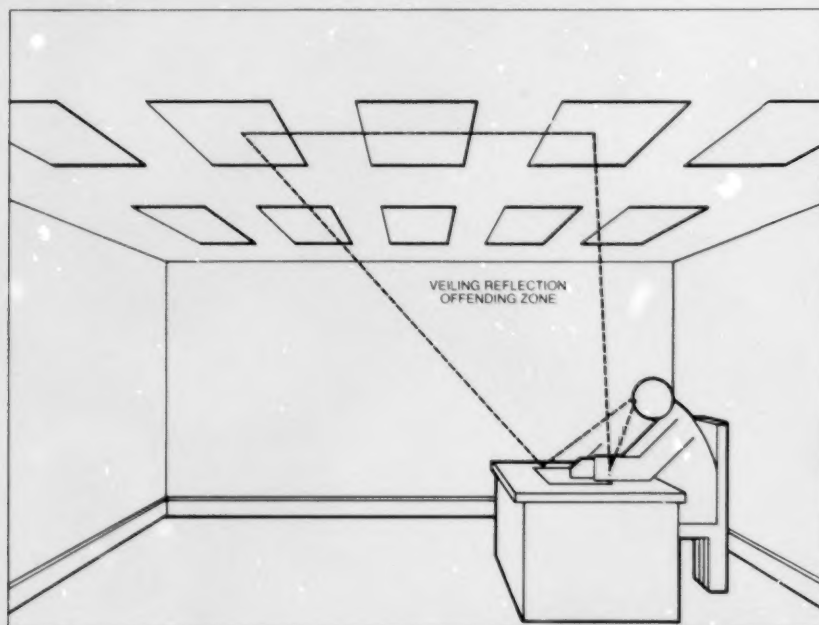


Figure 4: Veiling reflections occur when light from a source directly above or in front of a viewer bounces off the task (or workstation) surface and into the viewer's eyes.

KILOWATT-HOURS (KWH) VS. WATTS PER SQUARE FOOT (W/FT²)

Government agencies in particular have resorted to evaluating the efficiency of a lighting system on the basis of watts per square foot (W/ft²). The W/ft² of a given facility or space is easy to determine. One merely adds up the power requirements (wattages) of all lighting in the space and then divides by the total square footage involved. Thus, if there is a 50,000W (50kW) connected lighting load serving a 20,000 ft² space, it would be rated at 2.5W/ft².

The assumption underlying the use of W/ft² is that installations with a lower W/ft² rating are more efficient than those with higher W/ft² rating. This may not be the case, however, because electrical energy consumption is measured in kilowatt-hours (kWh), (i.e., load multiplied by time), not kW. Because time of use is not considered in a W/ft² calculation, it is entirely possible that a 3.5W/ft² installation may be far more efficient—and consume far less energy—than one rated at 2.5W/ft². For example, a facility may require that a certain area be illuminated 24 hours per day even though it is occupied for only eight. Special high-efficiency lighting suited solely for security purposes may be installed for use during the 16 non-occupied hours. The energy consumed by this system could be only 25% of the amount consumed by the overhead lighting used during occupied hours. This special lighting will save a considerable amount of energy. Nonetheless, it will elevate the area's W/ft² rating.

When applied properly by people trained to do so, W/ft² can be a useful tool. Unfortunately, there is reason to believe that the measure is being misapplied. When this occurs problems can result. For example, it may be assumed that an installation rated at 2.5W/ft² is efficient when, in fact, it may be wasteful. Nonetheless, because efficiency is assumed, no effort is made to attain savings.

It must be recognized that saving energy means reducing kWh (consumption). Reducing connected load is only one way of many to reduce consumption. Increasing connected load can be an energy-saver,

too, when the proper controls are applied to help assure savings.

CASE HISTORY

The Clarke School, a 28,912-square-foot facility in Swampscott, Massachusetts, was experiencing a vandalism problem. In one area, people were climbing onto the roof and ripping off shingles, resulting in damage-causing leaks as well as the need for frequent roof repairs. In addition, windows near the boiler room door were constantly being used for target practice. Altogether, it was estimated that vandalism damage amounted to more than \$1,000 per year.

Existing lighting consisted of four 300W lamps, two 150W lamps, three 100W lamps, and two 60W lamps—all incandescent—for a total connected load of 1.92 kW (1,920W). All were manually controlled and operated 12 hours per day, 4,380 hours per year. At an average rate of 0.067 per kilowatt hour (kWh), it was costing \$563 per year for energy. It was costing another \$62 or so for replacement bulbs.

It was decided to upgrade the system through reliance on low pressure sodium lamps. According to the Swampscott School Department's energy conservation manager, Richard F. Coletti, "We realized that the low pressure sodium lamps would render most of the colors illuminated as shades of gray or yellow, but this was fine for our purposes. We were more interested in deterrence than identification. We went ahead and replaced most of the existing incandescent lamps and fixtures with the LPS versions and also added photocells (one per low pressure sodium fixture) for automatic control. The photocell controls do more than just reduce total on-time. They also provide better security and safety during heavily overcast periods of a day."

The total installation was made in July 1979, at a cost of \$1,725, with the new system consisting of five 55W and two 35W low pressure sodium lamps, plus one 100W and two 60W incandescents. Altogether, the connected load is 740W, including low pressure sodium ballast losses. Mr. Coletti

estimates that use of the photocells reduces on-time hours of the low pressure sodium lamps by about 10%, for a system-wide savings of 7%. (The low pressure sodium load comprises about 70% of the total load; 70% x 10% = 7%.) As a result, the new system cuts energy consumption by 64.2%, as follows:

Before

1.92 kW x 4,380 hrs/yr =
8,409.6 kWh/yr

After

0.74 kW x 4,073 hrs/yr =
3,014 kWh/yr

Savings

Amount saved = 8,409.6 kWh/yr -
3,014.0 kWh/yr = 5,395.6 kWh/yr
Percent saved = 5,395.6 kWh/yr
- 8,409.6 kWh/yr = 64.2%

Energy costs were also reduced by 64.2% amounting to an annual savings of \$361 (at \$0.067/kWh). In addition, the cost of replacement lamps was reduced to \$42 per year, for an annual savings of \$20 not including the value of the 15 hours or so of maintenance labor time saved each year.

"Naturally, energy savings aren't worth a thing unless you get the job done," said Mr. Coletti, adding: "Very frankly, we would have been willing to spend more in energy if it would have saved us some of the vandalism expense. But in this case, because of the additional light output of the new lamps and fixtures, security lighting was improved, and not just be making it less expensive. In fact, since the installation was made, the only vandalism problem has been one broken window in two years. We estimated that as a 95% reduction in vandalism, worth an additional \$1,000 per year."

Overall, the full value of the savings amounts to:

Annual Energy Savings (at \$0.067 kWh)	\$361.00
Annual Maintenance Savings:	20.00
Annual Vandalism Savings:	\$1,000.00
TOTAL	\$1,381.00

As a result, payback occurred in just over one year (15 months), and the school is realizing an 80% annual return on investment.

GLOSSARY

GENERAL

Ballast: A device that modifies incoming voltage and current to provide the circuit conditions necessary to start and operate electric discharge lamps.

Beam Spread: The vertical and horizontal spread of a lighting beam (particularly an outdoor lighting beam) in degrees, bounded by the angle at which 10% of maximum candlepower occurs. (Maximum candlepower is the highest intensity in the beam.)

Brightness: As commonly applied, the intensity of the sensation which results from viewing a surface or space which directs light into the eyes.

Contrast: The relationship between the brightness of an object and its immediate background. An example of this would be the relationship between the letters printed on this page and the page itself. An example of poor contrast would be a third or fourth carbon copy of a purchase order or computer printout.

Diffuser: A device commonly put on the bottom and sides of a luminaire to redirect or spread the light from a source. It is used to reduce the brightness of the source and, in many cases, to control the direction of light emitted by the luminaire.

Electric Discharge Lighting: Lamps which provide light when an electric discharge excites the gases they contain. Commonly used electric discharge lamps include fluorescent, low pressure sodium, and HID sources.

Fixture: A luminaire.

Glare: A discomforting condition which occurs when a high brightness source contrasts with a low brightness background, making it difficult for eyes to adjust. High brightness alone does not cause glare.

HID: High intensity discharge lighting, including mercury vapor, metal halide and high pressure sodium light sources.

IES: Illuminating Engineering Society of North America.

Lamp: A light source, commonly called a bulb or tube.

LEMO: Lighting energy management option.

Lens: A glass or plastic shield that covers the bottom, and sometimes sides, of a luminaire to control the direction and/or brightness of the light as it comes out of the

luminaire. In many cases it also redirects light in specific patterns in order to achieve certain desired effects.

Louver: A series of baffles arranged in a geometric pattern to shield a lamp from view at certain angles to avoid glare from the bare lamp.

Light Trespass: A situation which occurs when, due to lack of adequate beam control, light from an outdoor source is distributed onto areas where the illumination is not wanted.

Luminaire: A complete lighting fixture including one or more lamps and a means for connection to a power source. Many luminaires also include one or more ballasts and elements to position and protect lamps and distribute their light.

Maintenance Factor: A multiplier which is applied to account for aging of the lamp (lamp lumen depreciation or LLD) and for dirt build-up on the luminaire (luminaire dirt and surface depreciation) during the period for which a lamp is in place. Lamp aging and luminaire dirt build-up both reduce light output, the amount of reduction increasing with time. In common practice, maintenance factors are applied to initial footcandles to derive the average lighting level over time or the minimum lighting level on the area being illuminated at the end of the maintenance period, depending on the factor used.

Nonuniform Lighting: A system wherein fixtures are located with respect to the tasks so more lighting falls on the tasks than on surrounding areas.

Payback: The amount of time required for a given investment to pay for itself. *Simple payback* is determined by dividing initial cost by annual cost-benefit (annual savings and/or additional income). Thus, the simple payback for an investment that costs \$1,000 and saves \$500 per year is two years. Other payback formulas are based on life-cycle costs divided by life-cycle benefits, in some cases discounting future savings and costs on the basis of their present value. (One dollar received one year from now is not as valuable as one dollar today because today's dollar could be invested, thus accruing additional value over a year's time. The present value of "future money" is determined by discounting it at the rate of return that could customarily be earned.)

Reflector: A device used to redirect the light from a lamp or luminaire by the process of reflection.

ROI (Return on Investment): The rate of return generated by a given investment. A \$1,000 investment in energy conservation that creates a \$400/year savings has a *simple ROI* of 40%.

Spacing-to-mounting-height Ratio: The ratio of the distance between the center point of luminaires to their mounting height above the work plane.

Spill Light: Lumens distributed by an outdoor luminaire or reflectorized lamp which are outside the beam spread.

Task Lighting: Lighting that falls on a given viewing task or object.

Uniform Lighting: A system wherein fixtures are located in a uniform grid-type pattern, so that most areas of a space receive approximately the same amount of illumination.

Veiling Reflection: A form of indirect glare that partially or totally obscures details by reducing contrast between the task surface and its background.

Work Plane: The plane at which work is performed and at which illumination is specified and measured.

QUANTITY OF LIGHT

Footcandles: The basic measure used to indicate level of illumination. One footcandle is equal to one unit of light flux (one lumen) distributed evenly over a one-square-foot surface area. Several different footcandle measures are used, as follows:

Minimum footcandles indicate the amount of light falling on that point of a surface with the least illumination.

Maximum footcandles indicate the amount of light falling on that point of a surface with the most illumination.

Average footcandles indicate the theoretical average amount of light falling on a surface, as derived by averaging the illumination falling on all points of the surface. Two systems may produce identical average footcandles while providing highly dissimilar illumination.

Footcandle (or uniformity) ratio represents the relationship between average footcandles and minimum footcandles (such as 3:1) or maximum footcandles and minimum footcandles (such as

6:1). The maximum/minimum ratio generally is preferred to average footcandles because average footcandles cannot be seen.

Initial footcandles are the minimum, maximum or average footcandles produced when lamps and luminaires are new.

Maintained footcandles are the minimum, maximum, or average footcandles over time calculated through application of a maintenance factor.

Horizontal footcandles are those measured on a horizontal surface, such as a street. All horizontal footcandles are in the same plane for the same surface. They can be added together arithmetically when more than one source provides light to the same surface.

Vertical footcandles are those measured on a vertical surface, such as a wall. Vertical footcandles may not all be in the same plane and therefore may not be additive in the way horizontal footcandles are.

LIGHTING EFFICIENCY

Efficiency: A general term used to indicate how much energy is required for performance of a given function. Several types of efficiencies must be considered.

Source efficiency is a measure indicating the efficiency of a lamp in terms of lumens (of light output) per watt (unit of input power). Source efficiency is more commonly known as *efficacy*, *luminous efficacy*, or *luminous efficiency*. Note that most types of lamps require a ballast for proper operation and that ballasts consume energy. Although ballast energy consumption is not generally included when identifying source efficiency, it must be considered in calculating energy consumption or the efficiency of a lighting system.

Coefficient of utilization (CU) indicates the percentage of lamp lumens falling on the work plane or area to be illuminated. Thus, if the lamps produce 10,000 lumens, and 7,000 lumens fall on the area to be illuminated, coefficient of utilization is 0.70 or 70%. Note that, for indoor applications, the CU of a given fixture will vary depending on factors such as room configuration and surface reflectances.

Coefficient of beam utilization is the percentage of outdoor lighting beam lumens falling on the area to be illuminated. Thus, if the beam spread contains 40,000

lumens and 30,000 lumens fall on the area to be illuminated, the coefficient of beam utilization is 75% (30,000 ÷ 40,000).

CASE HISTORY

New lighting installed in a Cedar Rapids, Iowa, YMCA is credited not only with reducing lighting expenses by 60%, but also with increasing swimming safety, enhancing the performance of swimmers, and improving the attitudes of staff.

Existing pool lighting at the Ellis Branch YMCA was due for replacement because the humid, chlorinated atmosphere was causing increased maintenance headaches and expense. The system consisted of 66 wall-mounted open-tube fluorescent fixtures with a shield for indirect lighting effect. Each fixture was equipped with two four-foot 40-watt lamps, less than half of which would be operational on any given day. At an average cost of six cents per kWh, the cost of energy consumption amounted to \$1,289 per year. The cost of replacement lamps and lamp replacement labor added another \$733 to the bill, with the cost of ballast replacement (\$462 per year) bringing the total annual expense to \$2,484.

According to Ron Foster, an engineer from Solon, Iowa, who designed the new system, "It would have cost about \$5,400 to replace the existing system. The new system decided upon cost \$3,962."

The new system consists of eight 400W metal halide lamps and enclosed fixtures mounted overhead. Its operating and maintenance cost is only about one-third that of the old system. Energy cost was cut to \$817 per year, representing a \$472, 37% annual savings. The cost of replacement lamps also is far less (\$71 vs. \$304 per year) because there are far fewer lamps and they last so much longer, due to the protection afforded by the new fixtures. (Due to lack of adequate protection, the heavily-chlorinated, humid atmosphere was causing fluorescent lamps to fail at about one-tenth of their rated lives.)

Mr. Foster asked those who use the pool area to let him know about the benefits provided by the new lighting. Those they wrote to him about include enhanced swimming safety, better attitudes among staff,

improved performance by instructors, better comprehension and execution by students, improved athletic performance by swimmers, and excellent attitudes among parents.

One instructor wrote, "The new pool lights have really made night guarding much safer. We don't have dark and light spots so we can see everywhere. When the weather becomes cloudy and dark, it becomes like day and much more pleasant to teach. When we turn the lights on, (the children) swim better and relax more. When they do that, the concentration and quality of swimming definitely improves."

Another instructor wrote, "I enjoy working under the new lights. It seems my eyes are not tired after working under them. The shadow-free lighting really helps my teaching. I can see what is going on under the water as my student is swimming. I also notice that people seem to be calmer in the evening during fun swims."

The aquatics coordinator said, "My attitude has really changed since we've gotten new lighting in the pool. They shine directly down so we are able to see into the water more clearly. It has enabled me to teach strokes better. Also, when life-guarding, it enables us to see the pool area as a whole better, which enables us to do our part in safety better."

And the senior program director commented, "All of our instructors, and myself as director, have received many comments from our members that the lighting system has made the pool environment much more conducive to learning and more comfortable for recreational swimming. I personally have noticed a great number of young students graduating sooner from the swimming skills classes this summer."

"Even if the new lighting system had been more costly to install and operate, the performance benefits derived would in my opinion have justified whatever additional expense was involved," Mr. Foster said.

CONDUCTING A LIGHTING ENERGY AUDIT

Excellent materials on conducting a lighting systems audit are available both from the Association of Physical Plant Administrators of Universities and Colleges and from the National Lighting Bureau. There is little need to elaborate here on the specific types of information to be recorded, such as that indicated in Figure 5. Several points are worthy of mention, however.

First, conduct a lighting energy audit. While generalized lighting system information may have been recorded at some earlier time, specific information is needed to help assure the effectiveness of results.

Second, physically inspect lighting systems. Even as-built drawings may not accurately portray what actually is installed.

In addition, only a physical inspection can reveal the condition of lighting equipment and the quality of maintenance being performed.

Third, avoid assumptions. For example, do not assume that lighting in a building is used eight hours per day just because the building is open from 9AM to 5PM. Observe how the lighting is used and when it is used.

(1) UNIT OR SPACE SERVED	(2) AREA (Ft ²)	(3) TYPE LUMINAIRE	(4) WATTS PER LUMINAIRE	(5) QUANTITY	(6) TOTAL WATTS
INTERIOR LIGHTING					
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
TOTAL	_____			_____	_____
EXTERIOR LIGHTING					
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
TOTAL	_____			_____	_____

Figure 5: Lighting Systems Audit Form

Fourth, assess the quality of lighting something which cannot be determined through analysis of numerical data. An "experienced eye" will be able to detect lighting systems which do not support func-

Fifth, consider the benefits of light-

(7)
WATTS
/Ft²

(8)
ANNUAL
HOURS
OF USE

(9)
ENERGY
CONSUMP.
(kWh)

(10)
LIGHTING
ENERGY
COST

(11)
METHOD
OF
CONTROL

(12)
ILLUM.
(fc)

LIGHTING ENERGY MANAGEMENT OPTIONS (LEMOs)

Lighting energy management options (LEMOs) are best discussed in terms of lighting system components, but—in practice—they are best considered in terms of an overall system. For example, we can discuss lamps as a separate entity, but the actual performance of a lamp depends on the type of fixture in which it is placed, the fixture's ballast and lens (or louver grid), the type of control applied, and the quality of maintenance that is or will be performed.

In short, lighting should be evaluated on a systematic basis, and LEMOs should be reviewed on the basis of the interrelationships of lighting system components, and the interrelationship between lighting and other systems. Many of the LEMOs discussed below are implemented for illustrative purposes in the calculation example given in the following section.

LAMPS

There currently are six families of lamps used for general lighting purposes:

incandescent, fluorescent, mercury vapor, metal halide, high pressure sodium and low pressure sodium. Their efficiency is measured in terms of lumens per watt (LPW), meaning light output divided by the power required for operation.

As shown in Table 1, the efficiency of lamps varies considerably both within and between the six categories. Note that the data also include ballast losses, the energy consumed (or lost) when the ballast transforms incoming voltage and current to make them suitable for lamp operation.

Lamp Selection Criteria

Although lamp efficiency is an important criterion in lamp selection, it is far from being the only criterion. *The general rule is to specify the most efficient lamp suitable for the application.*

Color Rendition: One of the other important lamp selection criteria is color rendition, meaning the manner in which light from the lamp affects colors of the illuminated objects.

New "color-improved" fluorescent and metal halide lamps provide color rendition that some feel is superior to incandescent. They, like most other types of lamps, produce what is called "white light." There are some exceptions, however.

High pressure sodium lamps emit what is called "golden white" light. Although they tend to distort some colors—for example, they give reds a brownish hue—all colors they illuminate remain recognizable. They are used extensively outdoors and are gaining continually more acceptance for indoor applications where color discrimination is not critical to task performance. They also are being mixed in with other lamps, such as metal halide, to create certain system-wide color effects. Interior design problems associated with their use are overcome easily, by making color selections in a space illuminated by high pressure sodium lamps.

Color-corrected high pressure sodium lamps are now available. Although their color rendering properties are similar to other white light sources, they are not as

Table 1: General Lighting Lamp/Ballast Characteristics¹

Type of Lamp	Wattage Range	Initial Lumens per Watt Including Ballast Losses ²	Average Rated Life (Hours)
Low Pressure Sodium	18–180	62–150	12,000–18,000
High Pressure Sodium	35–1,000	51–130	7,500–24,000 +
Metal Halide	175–1,500	69–115	7,500–20,000
Mercury Vapor			
Standard	40–1,000	24–60	12,000–24,000 +
Self-ballasted	160–1,250	14–25	12,000–20,000
Fluorescent			
Standard	20–215	63–95	9,000–20,000 +
Self-ballasted	8–44	22–50	7,500–18,000
Incandescent	60–1,500	13–24	750–3,500

Notes:

1. Data are based on the more commonly used lamps and are provided for comparison purposes only. Actual results to be derived depend on factors unique to the specific products and installation involved. Consult manufacturers for guidance.
2. Lumens (of light output) per watt (of power input) is a common measure of lamp efficiency (efficacy). Initial lumens per watt data are based upon the light output of lamps when new. The light output of most lamps declines with use. The efficiency of all lamps declines with use. The actual efficiency to be derived from a lamp depends on factors unique to an installation. The actual efficiency of a lighting system depends on far more than the efficiency of lamps or lamp/ballasts alone. More than lighting efficiency must be considered.

efficient, nor do they have as long a rated life as conventional high pressure sodium lamps.

Low pressure sodium lamps—the most efficient of all—tend to make all colors they illuminate appear as shades of gray or yellow. This restricts their application to areas where color discrimination is not important at all. They are used primarily for outdoor purposes. Indoors, they can be applied in areas such as storage rooms or warehouses, or in normally-occupied spaces where they can be used for security purposes during nonoccupied hours. Low pressure sodium lamps can also be mixed in with other lighting to elevate overall system efficiency.

Lamp Lumen Depreciation (LLD):

The light output of most lamps declines with use while their energy consumption remains constant. In some cases, a lamp's light output remains constant but its power requirements and energy consumption increase. In either case, lamp efficiency declines with use, for some at a much faster rate than others. The rate of efficiency loss can be more important than the lamp's rated life because it is generally considered to be good practice to replace a lamp before it burns out. This helps retain overall system efficiency as well as the quantity of illumination needed to derive effective safety and security, worker productivity, and other lighting benefits.

Rated Life: A lamp's rated life is determined by manufacturers based on standardized tests. It is that point in time when half the lamps of a large sample can be expected to have failed. It is used to indicate the amount of time that a lamp can be expected to function. As noted, the rate at which a lamp's light output diminishes should be considered in evaluating how long a lamp should be kept in place. It is

wasteful to keep using a lamp that has become inefficient.

Useful Life: Useful life indicates the amount of time that a lamp will be kept in place irrespective of its rated life. Useful life is established by the lighting system owner based on criteria he determines to be valid. The useful life of fluorescent lamps is generally considered to be 60-80% of rated life.

Lamp Shape: There are many different lamp shapes. Lamps can generally be categorized as point sources (bulbs) or linear sources (tubes). The light output of point sources, which are more compact than linear sources, is more easily controlled (directed). Nonetheless, the fixture is the key element in light distribution, and thus the primary factor in determining the amount of lamp light that becomes useful light.

Fixture Compatibility: In many cases the existing fixture is a limiting factor in that the lamp selected must be usable within it. It is not generally advisable to modify a fixture substantially, except to install different types of ballasts. Maximum lighting efficiency and benefits usually are derived when new fixtures are used.

Cost: Initial cost should not be a particularly important selection criterion. It only indicates how much a lamp costs to buy, whereas *life cycle cost (LCC)* indicates how much it costs to own and operate a lamp. The cost of ownership and operation includes initial lamp cost, as well as the cost of lamps to be used over a specified period of time, and the value of the energy the lamps will consume over that time. Depending on the installation involved, the number of lamps required to provide equivalent foot-candle levels, cost of fixtures and other factors also must be considered.

Strike/Restrike Time: HID lamps take several minutes to reach full light output when initially turned on. Restrike times generally are longer because lamps first must cool down. Devices—some wired into fixtures—are available to reduce strike and restrike times for some HID lamps. Only those which have been UL-approved should be used. (All lighting system components should be UL-approved.) Note that key-activated or time-delay switches can be used to prevent accidental actuation of HID switches.

Lamp LEMOs

The two predominant lamp LEMOs are direct substitution and use of new lamp/luminaire combinations.

Direct Substitution: Direct substitution involves nothing more than replacing one lamp with another designed for use in existing fixtures. In most cases direct substitution is performed to derive more lighting efficiency, either because the new lamp produces the same amount of light while consuming less energy, or because it produces far more light for the same amount of energy. Direct substitution may also be performed to obtain different color rendering properties or longer rated life.

Table 2 identifies some of the more common direct substitution possibilities, many of which have been made possible by the development of new lamps within the past few years. For example, ellipsoidal reflector (ER) lamps have been designed specifically for use in "high hat" (stack-baffled downlight) fixtures. A 75W ellipsoidal reflector will provide just as much light beneath a fixture as a 150W R-40 flood lamp because less light is trapped in the fixture itself (Figure 6). Impressive energy savings (50%) will result.

CASE HISTORY

Rutgers University retrofitted more than 3,300 dormitory hallway lighting fixtures, substituting 22W self-ballasted fluorescent lamps for 60W and 75W incandescent lamps. The total cost of the retrofit was \$56,501. Annual energy savings (at \$0.044/kWh) amount to \$54,770. The modification is saving Rutgers additional money because fewer replacement lamps must be purchased, stored and installed. (The new fluorescent lamps last approximately 15 times longer than the incandescent lamps they replaced.)

CASE HISTORY

Charles O. Spaulding, physical plant director, and Thomas McNeil, energy coordinator, were concerned about the lighting at the University of Massachusetts' College II, a 288,000-square-foot building consisting of classrooms, laboratories, gymnasium, lecture hall and cafeteria. The main lobbies and corridors were lighted with 277 recessed 100W incandescent fixtures and they said, "The low light level created a feeling of insecurity and there were constant maintenance problems."

The two decided to install 107 2'x2'

fluorescent fixtures. The cost of the retrofit was \$3,424. The value of annual energy savings amounted to \$3,980. In addition, they said, "The light output more than doubled, thereby increasing security; and the maintenance problem virtually disappeared."

Table 2: Lamp Interchangeability¹

Standard Lamp	Replacement Lamp	Wattage Savings ²	Comparative Light Output of Replacement Lamp ³	Value of Energy Savings Over Life of Replacement Lamp at \$0.06	Other Benefits ⁴
60W Incandescent	Self-Ballasted Fluorescent	42	+	\$ 18.90	X
100W Incandescent	Self-Ballasted Fluorescent	56	=	\$ 25.20	X
150W R-40 Flood Incandescent Downlight	75W ER-30 Incandescent Downlight	75	=	\$ 9.00	
	120W ER-40 Incandescent Downlight	30	++	\$ 3.60	X
120W PAR-38 Spot or Flood Incandescent	120W PAR-38 Spot or Flood Incandescent	30	=	\$ 3.60	
300W R-40 Flood Incandescent Downlight	120W ER-40 Incandescent Downlight	180	-	\$ 21.60	
500W Incandescent	450W Self-Ballasted Mercury Vapor ⁵	50	-	\$ 48.00	
1,000W Incandescent	750W Self-Ballasted Mercury Vapor ⁵	250	- -	\$240.00	
F-40 Fluorescent	F-40 Reduced-Wattage, High-Efficiency Fluorescent	7	=	\$ 8.40	
	F-40 Reduced-Wattage, High-Efficiency Color-Improved Fluorescent	7	-	\$ 8.40	
	F-40 High-Brightness Fluorescent	0	+	\$ 0.00	X
F-96 Fluorescent	F-96 Reduced-Wattage, High-Efficiency Fluorescent	16.5	-	\$ 17.82	
F-96 HO Fluorescent	F-96 HO Reduced-Wattage, High-Efficiency Fluorescent	16.5	-	\$ 17.82	
F-96 1,500 MA Fluorescent	F-96 1,500 MA Reduced-Wattage, High-Efficiency Fluorescent	30	-	\$ 20.25	
175W Mercury Vapor	150W Retrofit High Pressure Sodium	40	++	\$ 28.80	X
	175W Retrofit Metal Halide	0	++	\$ 0.00	X
250W Mercury Vapor	215W Retrofit High Pressure Sodium	65	++	\$ 46.80	X
400W Mercury Vapor	325W Retrofit Metal Halide	70	++	\$ 63.00	X
	400W Retrofit Metal Halide	0	++	\$ 0.00	X
	360W Retrofit High Pressure Sodium	60	++	\$ 57.60	X
1,000W Mercury Vapor	880W Retrofit High Pressure Sodium	160	++	\$ 51.00	X
1,000W Mercury Vapor	1,000 Retrofit Metal Halide	85	++	\$115.20	X

- Notes:**
1. All numbers shown are approximations, and in certain cases assumptions are made about the types of fixtures and other conditions involved. Consult manufacturers for accurate data relative to direct replacements possible for a given installation as well as any ballast, operating temperature or other restrictions which may apply.
 2. Wattage savings include ballast losses, where applicable. Actual ballast losses to be experienced depend on the specific type of ballast involved and operating conditions which affect its performance. In those cases where wattage savings exceed the difference in lamp wattage (if any), operation of the replacement lamp also has the effect of reducing ballast losses.
 3. Symbols used indicate the following: ++ (substantially more) + (more) = (about the same) - (less) - - (substantially less). Consult manufacturers for accurate information relative to conditions unique to the lamps and installations involved.
 4. Other benefits typically provided by retrofit lamps include reduced maintenance costs due to longer lamp life, improved productivity, safety/security, quality control, etc., due to higher light output, ability to reduce number of lamps installed systemwide due to higher output of retrofit lamps, and improved color rendition.
 5. For high voltages only.

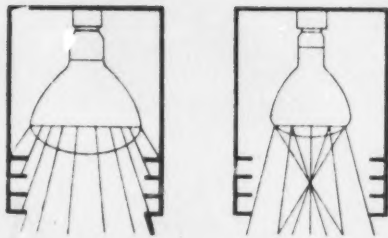


Figure 6: 75W elliptical reflector lamp (above) delivers about the same amount of light to the work plane as the standard 150W reflector lamp because much of the latter's output is trapped inside the stack-baffled downlight fixture.

High-efficiency, reduced-wattage fluorescent lamps also have been developed in response to rising energy costs. Their use can result in energy savings of as much as 20% per lamp, depending on the specific lamp and fixture employed, with only a slight light loss.

Self-ballasted fluorescent lamps have been developed for use in incandescent fixtures, and self-ballasted metal halide lamps are under development for the same purpose. Their use can slash lighting energy cost by as much as 70%, while also reducing the cost of replacement lamps and labor due to extended lamp life that is up to ten times longer than those they replace.

Metal halide and high pressure sodium lamps are available for use in most types of existing mercury vapor fixtures. They greatly increase the amount of light provided and in some cases reduce energy consumption as well. It may be possible to use such lamps and reduce the overall number of fixtures installed because of their additional light output. Careful analysis is needed before such changes are made.

Use of New Lamp/Luminaire Combination: Generally speaking, use of new lamps and fixtures maximizes both savings and benefits, because it helps assure maximum compatibility between lamp and fixture, and between the lamp/fixture combination and the space and tasks being illuminated.

Modifying an existing fixture to accept a new type of lamp is not recommended. The cost of performing the modification properly often is very high. The problems associated with performing the modification improperly impose the potential of even higher costs. As such, it usually is far more cost-effective, and far better results generally are obtained, when a new fixture is used.

Lamp Removal: Lamp removal is an acceptable LEMO *only* when a comprehensive analysis of lighting needs and the effect of implementing other LEMOs indicates that excess lighting otherwise will be provided. Unfortunately, lamp removal often is performed without study, in the name of energy conservation. As already indicated, this can have a serious effect on lighting benefits, such as productivity and safety/security. Note that there are alternatives to lamp removal. One of these is to rely on different control strategies which reduce light output, while also making additional light available if and when needed. Another is to use a new type of fluorescent lamp which, when installed in a two-lamp fixture, automatically reduces fixture light output—and energy consumption—by either one-third or one-half.

When removing fluorescent or HID lamps, the ballast should either be removed or disconnected in place. Split ballasting, discussed on page 20, should also be considered.

FIXTURES

Fixtures have a significant impact both on the efficiency of lighting and its quality. Although both lamps and ballasts technically are elements of a fixture, they are discussed separately.

Fixture Selection Criteria

Several criteria are used to characterize fixtures. The relative importance of any given criterion is determined by the application involved. In other words, a factor such as glare may be far more important in some applications than in others.

Coefficient of Utilization (CU): A fixture's efficiency is the ratio of its total light output to the raw light output of the lamps alone. Not all the light emitted from a fixture is usable, however. Indoors, some of it is absorbed by space surfaces and furnishings. Both indoors and outside, some of the light will be directed to areas where it is not needed.

Coefficient of utilization, or *CU*, is the term used to indicate the efficiency of a fixture in a space. *CU* is defined as the ratio of light from the fixture that reaches the work plane to light emitted by the lamps alone.

Fixture manufacturers determine the *CU* values of their products based on standardized tests. The *CU* ratings depend on conditions unique to the application, such as the configuration and surface reflectances of the space involved. Manufacturers' catalogs thus contain tables of *CU* values for each fixture, but all assume a uniform lighting layout. *CU* data for non-uniform layouts are best determined through use of computer analysis. Most major manufacturers will provide these studies without charge.

The *CU*s of different fixtures used for the same application in the same space may differ markedly due to the design and construction of the fixture, the nature of its reflective surfaces, and type of lens or louver grid (shielding and diffusing media) employed.

The importance of having an efficient luminaire is recognized quickly when one considers that a space requiring 100 fixtures each with a *CU* of 0.50 feasibly would require as few as 67 fixtures each with a *CU* of 0.75. Fewer fixtures result in both first-cost and life-cycle cost savings.

Visual Comfort Probability (VCP):

Visual comfort probability, or *VCP*, indicates the amount of glare a fixture is likely to produce. A *VCP* rating of 0.70 indicates that 70% of the people seated in the least desirable location in a space would find the specified lighting system comfortable.

VCP data, like *CU* data, are determined through use of standardized tests. The *VCP* rating of a given fixture will vary depending on factors unique to a space.

The importance of having a low-glare lighting system cannot be overemphasized. Glare creates distractions and is a primary cause of eye fatigue and accompanying headaches.

In fact, when people say, "There's too much light in here," they usually are reacting to glare and *not* to lighting levels. Lighting levels refer to the quantity of illumination, glare relates to the quality of illumination. Thus, the high beams of an oncoming auto cause glare at night but not during the day. The quantity of the headlights' output does not change from day to night. Rather, quality factors differ, due to daytime vs. nighttime luminance ratios.

Glare can erode student comprehension, employee productivity, and athletic performance. Glare from outdoor lighting has caused pedestrian and vehicular accidents and has even led to law suits.

Generally speaking, a fixture's VCP is inversely proportional to its CU. Nonetheless, some manufacturers offer high quality fixtures which provide both high efficiency and good glare control. Whenever appropriate, these are the fixtures that should be specified.

Resistance to Dirt Build-up: The dirtier and dustier the environment in which a luminaire is to be placed, the more important its ability to resist contaminant build-up. *Luminaire dirt depreciation (LDD)* refers to the rate at which light output is reduced as dirt accumulates on the interior surfaces of a fixture, including lamps. *Luminaire surface depreciation* indicates the degree to which a fixture's exterior surfaces are affected by airborne matter, an aesthetic concern.

Luminaire dirt depreciation along with LLD (lamp lumen depreciation) determine the frequency of maintenance required to maintain sufficient lighting. Very often designers will add spare capacity to a lighting system due to their assumption—usually justified—that maintenance will not be adequate.

Lens/Louver Grid: Most fixtures can be ordered with any one of several different lens or louver grid options offered by the manufacturer, or—in some cases—with nonstandard materials which manufacturers obtain through special order. Some fixtures are designed for use without any type of shielding or diffusing media. Generally speaking, these are used at relatively high mounting heights where glare presents less of a problem and lamps are not likely to be damaged.

Lenses are made of glass or plastic. Most are fabricated in such a way as to distribute light in specific patterns. A given lens will have different effects in different fixtures, however, because the shape of a luminaire and the nature of its reflective surfaces also contribute to control of light distribution.

Lenses and louver grids also affect veiling reflections. As already noted, they reduce contrast between the task foreground and background, thus making it more difficult and time-consuming to complete a task, while also increasing the likelihood of errors. In many cases observers are unaware of veiling reflections, making the problem that much more difficult to detect. Because contrast rendition improves when more light is provided, reducing veiling reflections provides the same

benefits as increased illumination. As such, when veiling reflections are reduced, lighting levels often can be reduced as well, thus resulting in better seeing conditions and less energy consumption.

Different types of lenses, such as those which provide batwing distribution (Figure 7), help reduce the incidence of veiling reflections. Polarized lighting panels can also ease the problem, as can certain types of louver grids.

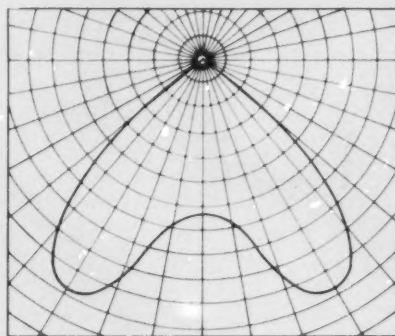


Figure 7: A typical batwing distribution is designed to deliver light at angles less likely to produce veiling reflections.

Special lenses can be useful for vertical tasks, because they distribute more light from top to bottom than from side to side. Merely adding these lenses or louver grids to existing fixtures will not necessarily obtain the desired result, however. For maximum effectiveness, the lens or louver grid must be compatible with the fixture being used.

Generally speaking, the distribution of light is even more important outdoors than indoors, because there are no walls or ceilings to be used for purposes of control. Do note that special lenses have been designed for outdoor areas that are particularly subject to vandalism problems. Some are tough enough to withstand even .22 caliber bullets.

Mobility: Many indoor fixtures are designed for drop-in installation, meaning they can be used in a standard-sized suspended ceiling grid. Others are designed for permanent flush mounting against a ceiling, or for suspension by a pendant or chain. Track lighting affords excellent fixture mobility,

thus permitting maintenance of effective nonuniform lighting despite changes to workstation locations or tasks. A new type of track lighting uses an electrified suspended-ceiling support grid to which fixtures can be flush-mounted.

Flexible wiring, also called modular wiring, is a special type of branch wiring that should be considered when new construction or substantial remodeling is involved (Figure 8). Factory-assembled branch wiring modules are used so fixtures can be plug-connected. If they have to be moved, they are simply unplugged, relocated, and plugged back in. Plugs are designed to eliminate the possibility of improper connections. Fixtures can be ordered prewired for whatever type of flexible wiring system is employed. The fixture mobility afforded by this type of system facilitates use of nonuniform lighting. Fixtures can be located where they are needed, thus providing better quality illumination while also minimizing energy consumption. Manufacturers also claim that use of this approach results in tax benefits. Because the branch wiring can be removed and used elsewhere, they state, the wiring and fixtures are not improvements to real property and thus are subject to rapid depreciation and tax credits. In addition, this type of lighting feasibly could be obtained through lease, thus reducing capital requirements.

Heat Removal: Lighting system heat is a particular problem in warmer parts of the nation and in the interior zones of larger buildings which often use cooling year-round to offset heat gains from lighting, people and equipment.

Special heat-removal and air-handling fixtures (Figure 9) are available to remove lighting system heat before it enters a space. When this heat is removed, far less cooling and ventilation are required. When new construction or substantial remodeling is involved, use of heat-removal or air-handling fixtures may permit specification of smaller and more efficient cooling systems to maintain equivalent comfort levels. In addition, removing lighting heat reduces the mean radiant temperature of the ceiling, increasing comfort, and also improves lamp efficiency and extends ballast life. In some cases, the lighting system heat which is removed can be moved to other areas or reclaimed for other purposes, saving even more energy.

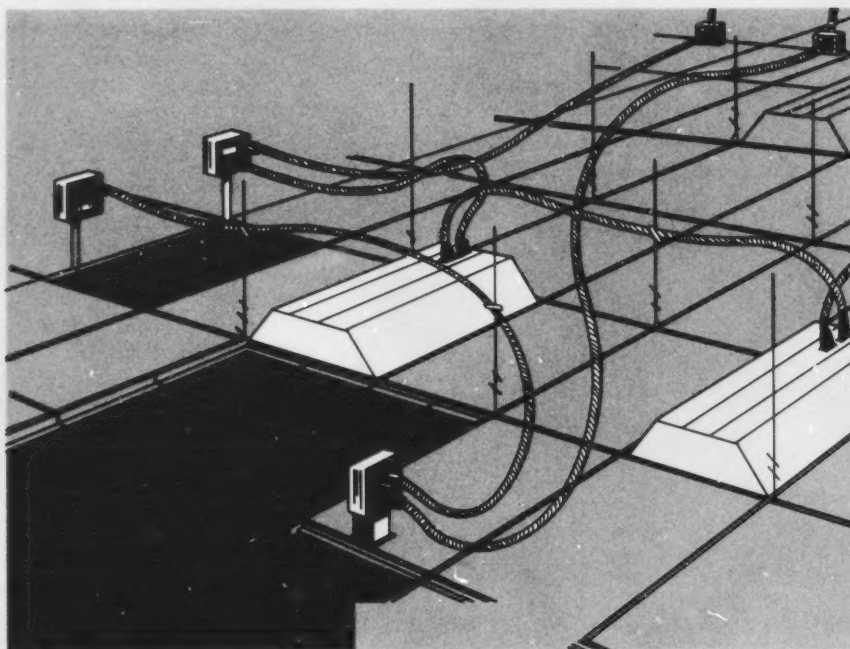


Figure 8: Flexible (Modular) Wiring System

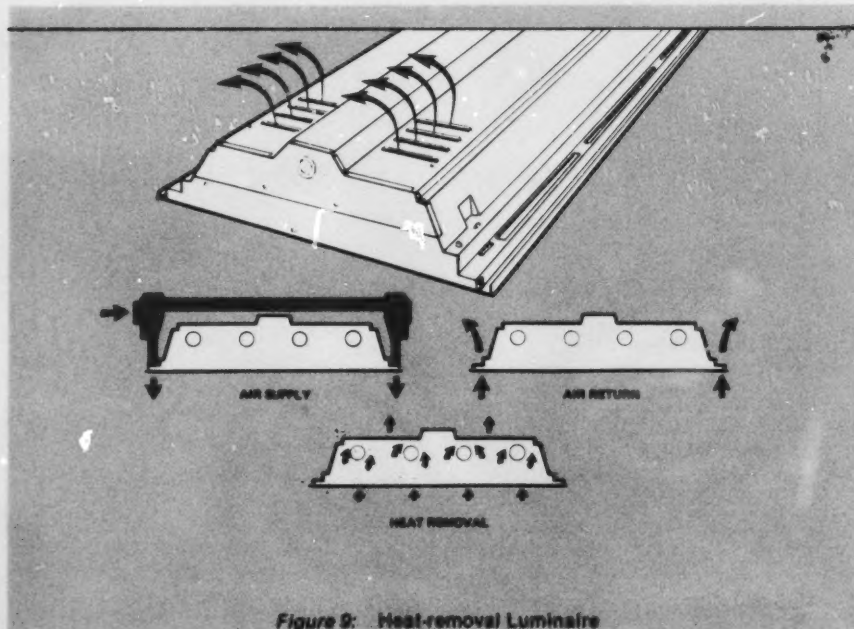


Figure 9: Heat-removal Luminaire

Fixture LEMOs

Some of the different fixture LEMOs you may wish to consider are indicated below. Those which relate to maintenance are covered elsewhere.

Fixture Replacement: Replacing old fixtures with new ones generally is the single most effective fixture LEMO because it helps assure mutual compatibility of the fixture, lamps, lens or louver grid, ballasts and the tasks. Fixture replacement should be considered when the reflective surfaces of existing fixtures have become dulled or when new fixtures can provide cost-effective advantages that cannot be obtained through application of other luminaire LEMOs.

Although fixture replacement may require a somewhat substantial capital outlay, the energy dollar savings to be derived can result in very rapid paybacks. The dollar value of benefits such as improved productivity, better safety/security, and others, can shorten paybacks even more.

Lens/Louver Grid Replacement: The lens or louver grid should be changed when a new one will provide more beneficial results. In all cases, lenses that have become yellowed should be discarded because they absorb too much light, reduce lighting quality and detract from overall space appearance. Do not convert from plastic lenses to glass lenses unless you first assure that the fixture can support the additional weight without problems.

Lens/Louver Grid Removal or Addition: Removal of a lens or louver grid generally is not a recommended LEMO. While it will increase a fixture's efficiency, it will not necessarily increase its CU by a comparable amount, and it almost definitely will create a glare problem. It usually is difficult to add a lens or louver grid to a fixture that was not designed to contain one.

Fixture Mounting Height Modification: Indoors, it may be possible to lower a fixture's mounting height to put more light on a task. As such, fixture light output can be reduced and still provide equal or even more lighting.

Outdoors, it is common to raise the fixture mounting heights. This permits use of larger, more efficient lamps, thus reducing the number of fixtures and/or poles otherwise required. This approach requires particularly careful attention to fixture selection, to help assure proper control of light distribution.

Fixture Relocation: If fixtures are causing veiling reflections, it may be possible to move them so their light falls across the task surface perpendicular to the viewer's line of sight. It may also be possible to simply relocate the workstation.

In some cases it is difficult and costly to relocate a luminaire. This is why, prior to the advent of flexible wiring techniques, uniform lighting was used so extensively. Although it had its aesthetic drawbacks, it was capable of providing the quantity of light needed in almost any area of a space. Today, given the high cost of energy, it may be worthwhile to investigate new approaches, especially for buildings likely to remain in use for many years to come. Note, however, that uniform lighting still is best for areas that are densely occupied.

BALLASTS

Significant progress has been made in the design and development of more efficient fluorescent ballasts. High-efficiency fluorescent ballasts for use with standard lamps can reduce lighting energy consumption by as much as 9% due to decreased wattage loss within the steel core and copper windings. The lower operating temperature of these new ballasts results in an average life that is two to three times longer than the 12-15 years of their conventional counterparts.

Reduced light output ballasts

reduce energy consumption by reducing the amount of current sent to the lamps. A 20% reduction is typical. Because light output is reduced by a corresponding percentage, these ballasts should be used *only* if reduced light output is compatible with needs.

Dual-level ballasts permit the option of full light output or reduced light output and energy consumption. Light level selection may be effected through rewiring, by reversing a plug-set, or by low voltage or wireless activation of relays. Standard dual-level ballasts permit a choice of 100% of output or 50% of output. Other reductions are possible through special order.

Dimming ballasts for use with fluorescent lamps are available. Other dimming approaches can be considered as well, as discussed elsewhere.

New fluorescent systems using both *electromagnetic and electronic ballasts* have been introduced recently. They increase system lumens per watt, thus per-

mitting a choice of fewer watts per fixture or fewer fixtures to obtain the same amount of delivered light. Some of these systems require special lamps which are not interchangeable with regular lamps.

Ballast LEMOs

Reballasting with high-efficiency fluorescent ballasts is the most commonly applied ballast LEMO. It is most economical to install these new ballasts when the existing ones are at or near the end of their usefulness. In this way the cost of reballasting is limited to the premium paid for higher efficiency; the labor and material would have been expended in any event.

Where extensive hours of operation are required and/or a relatively high electricity rate is in effect, it may pay to install high-efficiency ballasts even though the existing ones have several years of life remaining. In making calculations, it is essential to consider the cost avoided by not having to reballast as frequently.

CONTROLS

Controls can be divided into two basic categories: manual and automatic.

Manual Controls

A *circuit breaker* installed at a central panelboard for many years was the most common lighting control. Given the large number of fixtures typically operated by each switch, and its remote location, the lighting it controls usually is either all on or all off, despite the fact that circumstances may merit more selective, efficient usage. As a result, circuit breaker control is no longer used as the only means of control to any appreciable extent in new buildings.

AC Snap Switches: Local AC *snap switches*—common wall switches—permit selective use of lighting. Their benefits can be attained only when they are used properly. Rewiring can be performed so that each local switch controls only ten or so fixtures. Another alternative is to use two switches per row, so that each controls every other fixture. In that way, all the fixtures in the row are kept on when both switches are activated; 50% of light output is provided when only one is on.

Key-activated AC Switches: These are the same as AC snap switches, except

that a key is required to turn lights off and on. They are used to prevent unauthorized use of certain lighting circuits, and are particularly recommended for use with HID light sources.

Telephone Signal-activated Controls: Used with push-button telephones, these devices permit remote control of individual lighting installations. The user dials the telephone number of the control device, hears a beep, and then punches in a code. The code used causes lighting to be activated, or may permit use of local manual controls, often for only a predetermined period of time.

Low Voltage Switching Systems: These consist of magnetic relays and transformers that produce 24V or less, and on/off switches that are interconnected by low voltage wiring. When a switch is activated, it sends a low voltage "command" to the relay which, in turn, switches line voltage and current. Any fixture or group of fixtures (up to branch circuit capacity) can be grouped on a single relay. Because voltage drop presents no problem, low voltage switching permits control of one load from multiple locations, or—conversely—multiple loads from one central location, with or without local overrides.

Dimmers: Solid-state manual dimmers are available for incandescent and fluorescent lighting, as well as some HID sources. Some fluorescent dimming systems work in conjunction with a special dimming ballast or a solid-state control package that replaces a standard ballast. Others rely on an electronics package that operates with a standard ballast. All save energy when the lights are dimmed. Lamp and ballast manufacturers should be consulted about the effects of using such devices with their products.

Ballast Load Switching Systems: A ballast load switching system used with 120V fluorescent lighting (Figure 10) provides an alternative to local on/off switching.

The system is manually controlled by use of toggle switches located on the control panel or at a convenient remote location. A transmitter emits a continuous signal to receivers over existing lighting circuitry, thus eliminating the expense of rewiring. Note that automatic operation can be created through application of devices such as time switches, photocells and computer controls.

CASE HISTORY

Vandalism and rising energy costs were causing increased recreation lighting maintenance expenses for Farmers Branch, Texas, a city with a population of some 27,000 located on the outskirts of Dallas. During 1976-77, unauthorized use and misuse of athletic facility lighting systems cost approximately \$4,500. One act of vandalism to switchgear cost \$1,000. In addition, tennis court lighting was wasting energy. Time switches activated the "on" switch at 7PM, and shut the system down at 11PM. Tennis players were relied upon to push the "off" button when they were through with the courts, most did not.

To compound future costs problems, the city was in the process of adding seven lighted tennis courts over a two-year period and anticipated a need for up to 12 new athletic fields. Existing maintenance and

lighting energy bills were approximately \$1,000 per field per year. When inflation figures were plugged into current costs, prospective costs for the new courts and fields went "out of sight."

Staff members of the Parks & Recreation Department and the Public Works Department developed solutions.

At the tennis courts, a time switch opens electrical circuits at 7PM. When the "on" button is pushed there is an hour of uninterrupted light. When there are four minutes left in the hour, a buzzer sounds indicating that players then have four minutes to push the "on" button. If the button is not pushed the system shuts itself down. The master time control deactivates the entire system at 11PM.

All switchgear for the athletic fields was placed in a 10- by 12-foot utility building with steel doors. Remote controlling devices were added to the switching systems. In

practice, an athletic league representative phones the Parks & Recreation Department to request a field for a given date and time. A recreation department employee then makes a phone call from a pushbutton phone to the controllers located in the concrete utility building along with all the switchgear. The telephone service to each controller is an unlisted business line number. A standard wall telephone is mounted inside the box and can be used for maintenance calls. The phone call activates the device which answers with a short "beep." The employee then enters a code. If the code is correct, the controller gives a second "beep" and reverts to control mode, so lighting can be turned on or off.

Both the tennis court and athletic field lighting systems have been in service since 1978. In the ensuing years Farmers Branch has experienced no vandalism or misuse of any of the lighting equipment.

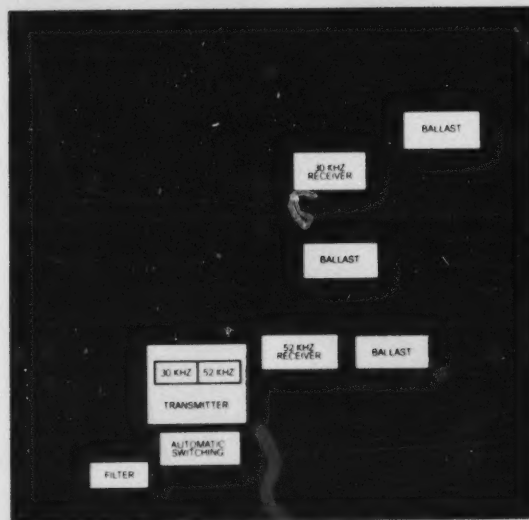


Figure 10: Ballast Load Switching System Schematic

Automatic Controls

Automatic controls have gained popularity for several reasons. First, like manual controls, they provide lighting system flexibility while saving energy at the same time. Second, they provide reliability because they do not depend on the human memory for proper operation. Third, automatic controls can do more than manual controls alone.

Door-activated Controls: Applied mostly for closets and other seldom-used areas, they activate lighting when the door is opened, deactivate it when the door is closed. Similar switches will activate lighting when the door is open and keep it on for a period of time whether or not the door is closed.

Timeclocks (Time Switches): Applied extensively for outdoor lighting, they also have their place indoors, to deactivate all

lighting in a given area at a preset time. An astronomic dial is often used with timeclocks specified for outdoor use. This feature adjusts the control for changing hours of daylight and darkness during the year, and some can even account for leap year. Many come equipped with battery packs or spring-mounted mechanisms to maintain calibration despite brownouts or blackouts. Most are programmable on a weekly basis.

Photocell Controls: Designed to control lighting based on ambient lighting levels, they are used extensively outdoors. They are also used indoors, particularly to control lighting fixtures installed near windows and skylights.

Photocells can also be used indoors to create multiple level switching through split ballasting. In the arrangement shown in Figure 11, for example, each ballast controls one lamp in the fixture where the ballast is located and one lamp in the adjacent fixture. Thus, when the ambient lighting level is below the predetermined minimum, all lamps are activated. When the ambient lighting level increases to a predetermined point above the minimum but below the maximum, the "A" ballasts (or "B" ballasts) are activated, creating a 50% lighting level. When the maximum ambient level is achieved, all electric illumination is deactivated.

Photocell/Timeclock Combination Controls: Applied outdoors, the timeclock portion of the control keeps lighting deacti-

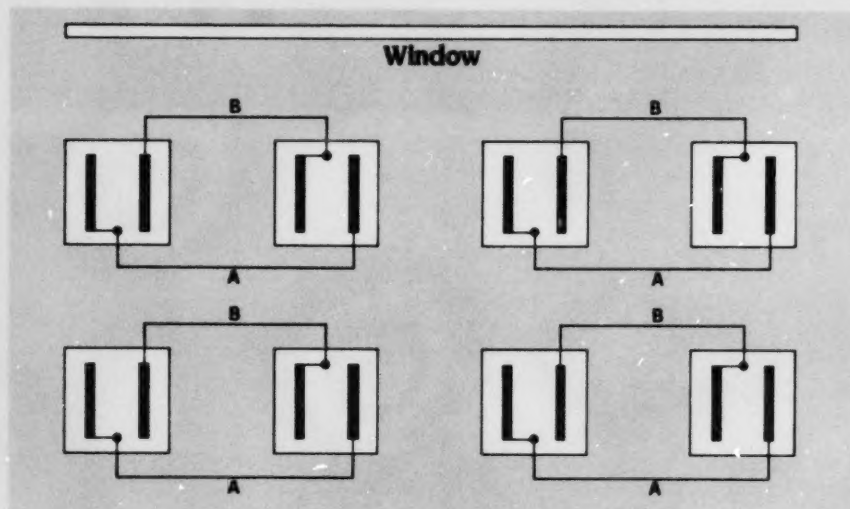


Figure 11: Photocell-based Multiple-level Switching Layout

uated for a given period of time, such as midnight to 6 AM. At all other times lighting is controlled by the photocell.

Dimmer/Photocell Combination

Controls: These are used for two purposes. The first accounts for the fact that lamps' initial lumen output usually provides more light than needed. Accordingly, the control reduces light output (and energy consumption) of new lamps, then provides more power as lamps age, so that light output remains about constant during lamps' useful lives.

The second use of dimmer/photocell combination controls affects fixtures near windows or skylights. As the amount of daylighting increases, the amount of light from fixtures is decreased, and *vice versa*, so that the amount of lighting in the area remains about constant at all times.

Dimmer/Timeclock Combination

Controls: These controls are applied for those areas where lighting needs differ during predetermined portions of a day. Lighting levels are adjusted by the time-clock portion of the control.

Radio-controlled HPS Ballast Systems:

Similar in concept and effect to a ballast load switching system, this device (Figure 12) relies on a wireless radio signal and a fully automated central control. (It is available at this time only for certain types of high pressure sodium systems.) An operator enters the desired lighting control scheme into the control console's memory via a keyboard. Radio control signals then are transmitted at the times established to receivers mounted in fixtures' ballast housings. The signals are transmitted to a microprocessor that operates the ballast to the appropriate wattage and lighting levels.

Personnel Detection Controls: These are designed to stop and start lighting based on the presence of people. Four types are used.

Ultrasonic controls are motion-detecting devices that turn lighting on when motion is sensed, off when no motion is detected.

Passive infrared controls activate lighting when they detect infrared energy given off by humans.

Active infrared controls operate like radar by transmitting and receiving beams. They activate lighting when a change in reflected light is detected.

Acoustic controls activate and deactivate lighting based on sounds within a prescribed range of frequencies limited to "human activities."

Personnel detection controls can be used in a variety of spaces. Note that they in some cases can be integrated with in-space HVAC units as well as motorized dampers of multizone central heating and cooling plants. They can also be used in conjunction with dimmers and as elements of security systems.

Centralized Programmable Lighting Controls:

Centralized systems (Figure 13) can be used to control all interior and exterior lighting and are particularly suited for colleges and universities. Typical components of such systems include the central controller through which a control program is entered via a keyboard. Controllers can also display the off/on status of relays. Transceivers accept signals from the control unit and, in turn, operate the relays with which they are interconnected. Some systems can accept manual override through direct activation at the keyboard or through

use of a pushbutton telephone. Printers can be integrated with the system to provide a hard copy record of activity.

Centralized programmable lighting controls can be used to control loads in addition to lighting. Similarly, *centralized load programmers* and overall *building control and monitoring systems*, used primarily for HVAC loads, can also be used for lighting loads.

Control LEMOs

Application of any of the controls discussed above, except circuit breakers, constitutes a control LEMO. Two LEMOs which should be considered when manual controls are applied are described below. The cost associated with these LEMOs should be considered before making a control LEMO decision.

Usage Schedules: The lighting energy audit will indicate how and where lighting is used. Consider how unnecessary usage can be avoided. For example, if clean-up crews normally perform their work in all areas at the same time, consider having all personnel start at one end and move toward the other, turning lights off and on as they move. If all personnel take lunch at the same time, encourage them to turn off lighting—or a portion of it—until they return.

To implement this type of routine, provide individuals with a usage schedule that identifies which lights should be on at certain times and off at others. This can be particularly helpful for those who work after-hours or who arrive early, especially if they also are responsible for turning outdoor lighting off and on. In some cases they may turn indoor lighting on a few minutes early each day just for the sake of convenience. Relying on usage schedules can discourage such wastefulness. To help make implementation easier, it may be appropriate to color-code switches in conjunction with the usage schedule.

Campaigns for Better Usage: Lighting switch stickers and posters mounted in strategic locations can be effective motivational reminders. Posters may even be more effective when they provide facts about lighting energy consumption, for example, how much can be saved overall per year just by remembering to turn lights off during lunch hour.

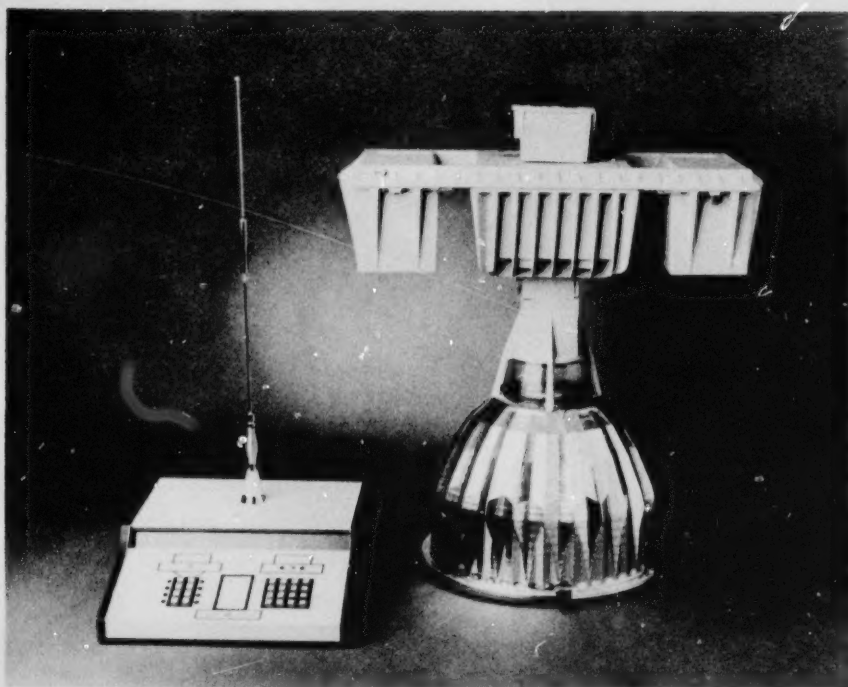


Figure 12: Radio-controlled HPS Ballast System

MAINTENANCE

It is the goal of a lighting designer to create a lighting system that provides the amount of light needed at all times. If it is assumed that lighting system maintenance will not be performed well—which is usually the case—the lighting designer will provide additional fixtures and lamps to compensate for dirt build-up on lamps and fixtures, and for the reduced light output of lamps left in place until they burn out. If high quality planned lighting system maintenance is to be provided, however, this additional lighting is not needed. Thus, if an existing lighting system was designed under the assumption that poor maintenance would be performed, and if at some future date high quality maintenance is performed, as much as 10% or perhaps even more of the installed lighting can be removed. The removal process should be selective in nature, to help assure that the geometry of the system remains adequate to meet needs.

Maintenance LEMOs

Several steps can be taken to improve maintenance and save energy. Very often the energy savings will be accompanied by better lighting and more lighting benefits.

Regular Cleaning: Regular cleaning is a sound investment. Generally speaking, lamps and fixtures should be cleaned at least once a year; more frequently depending on the amount of dust, dirt and other matter in the air. Figure 14 indicates causes of light loss and suggested schedules for taking specific maintenance action.

Early Lamp Replacement: As already discussed, it is beneficial to replace lamps at the end of their useful life rather than at the end of their rated life. When lamps are removed before they burn out, the average amount of light they produce while in place is increased. Thus, if a lamp produces 3,000 lumens when new and 1,500 lumens just before burn-out, its average lumen output, for purposes of this discussion, would be 2,250 lumens. (In fact, average lumen output depends on the actual aging characteristics of a given type of lamp.) If the lamp is replaced after lumen output has dropped to 2,100 lumens, the average output—again, for purpose of this discussion—would be 2,550. If only a 2,250 output is desired, a smaller wattage lamp may be appropriate.

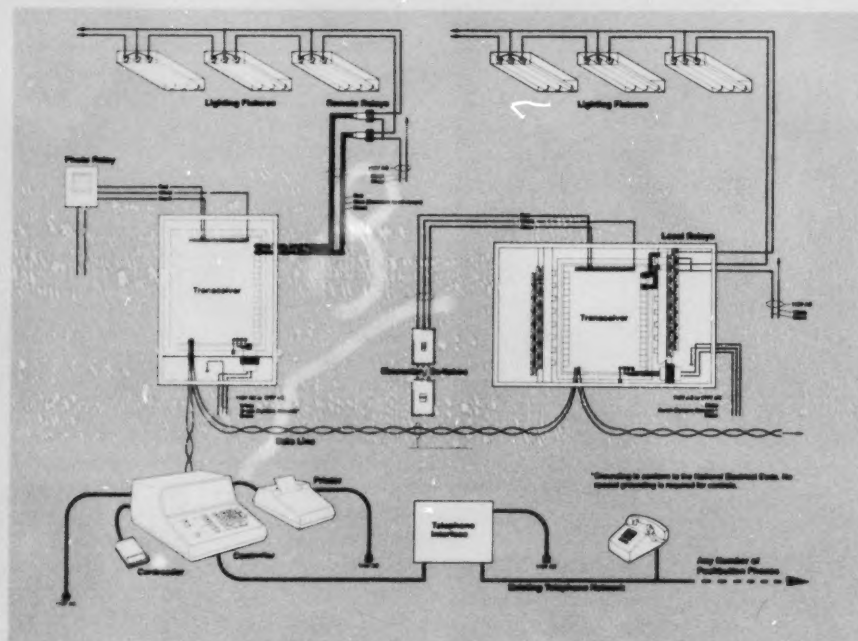


Figure 13: Centralized Programmable Lighting Control System

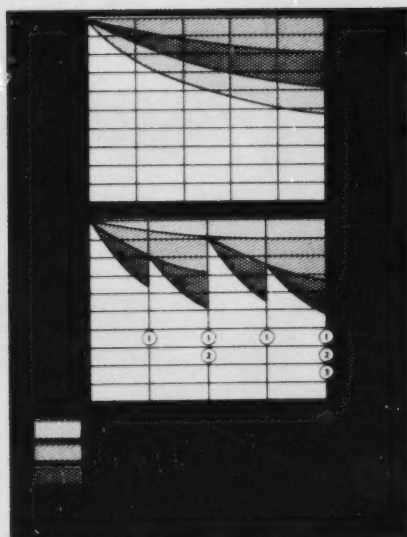


Figure 14: Upper graph curves show typical percentage losses of useful light plotted against time. Lower graph curves show the cause of loss of useful light and the effect of maintenance procedures in restoring the useful light.

On a systematic basis, however, lamp removal usually is performed.

In larger facilities it is virtually impossible to keep track of when lamps were last replaced. Group relamping can solve this problem and create other benefits as well.

Group Relamping: Group relamping involves the replacement of all lamps in a system, or all lamps in a large area, at the same time. While this will not eliminate the

need for occasional spot relamping, it does greatly reduce the cost of lamp replacement labor. It takes about 30 minutes to change a lamp on a spot relamping basis, due to the time required to fetch a lamp from inventory, set up equipment, and so on. When a group relamping is performed, all labor, equipment and material are assembled for the purpose—usually after normal hours—and the task takes about 3 minutes per lamp. This can mean a 90% savings in the cost of lamp replacement labor. When early lamp replacement and group relamping are combined, the average light output of the system is increased. It is this increase which, more so than other maintenance LEMOs, can permit the reduction of existing fixtures and/or lamps while retaining existing illumination levels. Although 10% savings are common, much higher savings have been reported.

Other benefits provided by group relamping include reduced lamp storage requirements and breakage, and better quality, more even lighting from lamps that are aging at the same rate. In many cases, group relamping also makes it feasible to rely on contract lighting maintenance for indoor purposes, just as many facilities now rely on it for outdoor lighting.

OTHER LEMOS

Several other LEMOs can be considered. These include:

Painting

The color of the ceiling, walls, equipment and other room surfaces can have a major impact on lighting efficiency. A review of CU data provided by fixture manufacturers shows that CUs rise dramatically as space finishes become lighter and more reflective. Painting has other benefits, too, including enhanced aesthetics and improved safety, for example, when moving parts of equipment are painted different colors, thus making the moving parts more visible.

Daylighting

Although the application of daylighting—natural light through windows and skylights—is growing in popularity, its use requires careful analysis.

Light entering through windows brings heat with it. Thus, the value of the energy saved on lighting and cooling (of the lighting load) must be compared to the cost of cooling the additional solar load.

The problem of glare must be considered closely. The quality of sunlight is variable and usually depends on the exposure direction of the windows through which it enters and the season of the year. Note that windows must be kept cleaner than usual. If not, smudges and dirt will cause glare and other distractions.

Use of daylighting also may require use of solar controls, such as movable drapes or blinds, or movable overhangs or awnings. In addition, the manner in which lighting will be controlled during partly cloudy days must be considered. Combination dimmer/photocell controls are recommended for this purpose. Their cost must be considered in the analysis.

CASE HISTORY

Installation of outdoor lighting has more than doubled overall use of a high school athletic stadium, has almost tripled fan attendance at football games, has increased ticket sales revenue, and may even be responsible for improved performance by some of the student athletes.

Coaches, parents and students had for several years been urging the Niles Township (Illinois) High School Board to install outdoor lighting for one of the school system's sports stadiums. Because budgetary limitations made it impossible to comply with the requests, supporters of the project—with the approval of the school board—established the "Stadium Light Brigade" to raise funds and obtain donations of equipment. They achieved their goals in less than one year.

The system, designed for the township by a manufacturer of outdoor lighting equipment, consists of 36 1,500-watt metal halide lamps mounted on six 65-foot steel poles. Two poles, with eight fixtures on each, are located at the midfield stripe and are set back 130 feet from the sidelines. Four poles are located near the end zones and have five lamps each. They are set back 40 feet.

John P. Nix, supervisor of buildings and grounds for the Niles Township High Schools, said that the Light Brigade spent a

total of \$53,253 on the system; the value of donated services and equipment was almost \$42,000, including the steel poles (worth \$20,000) donated by a bank that had held them as security on a defaulted loan.

To keep costs to a minimum, the school chose to act as its own general contractor for the lighting installation. According to Mr. Nix, "Our personnel quickly learned the methodology of assembling the poles, mounting the lighting fixtures and aiming the lights. With a little assistance from the math department, we were also able to calculate the correct angles at which to set the fixtures from left to right and horizontally. For the most part, the installation was rather routine. It consisted of trenching, laying of conduit, the installation of electrical panels, assembling of poles and fixtures and pulling of the necessary wire." He estimated that the annual owning and operating cost of the system amount to \$1,460 per year, plus \$3.60 for each hour the lighting system is on.

The school's primary motivation for installation of the stadium lighting system was to attain greater use of existing facilities, to make it more convenient for the working parents in the community to attend athletic competitions and to provide a community resource that could be used for a variety of activities. Mr. Nix noted that goals were met beyond expectations. Fan participation at football games has almost tripled since the lighting was installed, and additional revenue generated from ticket sales—some \$5,000 per year—is far more than enough to pay the operating costs. (If the school board had to bear the expense of the installation, payback would have occurred probably within 12 years or so.)

Mr. Nix went on to note that "overall use of the stadium has more than doubled in the number of events per year and requests for future activities and events indicate that, in the future, there will be even more intense use. It would be nice to also report that the won/loss records of our football teams improved under the lights. However, even though some of the lighting advocates may have secretly expected this, statistics to date do not bear it out. There is always next year, of course! And while we cannot report any great improvement in our football teams under the lights, the track coaches report significant improvement in the performance of track teams. Whether this is due to the lighting, the increased fan support or less wind resistance at night, is not known at this time."

CASE HISTORY

William F. Maillette, physical plant director for Bryant College (Smithfield, Rhode Island) was concerned about the quality of lighting and its energy consumption both along the school's main entrance and in the commuter parking lot. Changes were made in November, 1980, when high pressure sodium lighting was substituted for mercury vapor lamps.

Mr. Maillette estimates that the energy savings have been worth approximately \$3,000 per year. In addition, accidents in the parking lot and vandalism were both cut by 90%, and security was improved by 50%. According to Mr. Maillette:

"Reduction in accidents and vandalism in the parking areas was not an expected benefit. Since we are a rural campus located within fifteen minutes of a metropolitan area, we have, in the past, been subject to acts of vandalism during the evening hours (6:00 p.m. to 11:00 p.m.) when some 2,000 cars are on campus. These cars belong to commuters attending night classes and, as such, were targets. With the new lighting, a sharp reduction in vandalism has been noticed and we think it is just a case of too much illumination, eliminating any measure of protection for would-be vandals.

"The aesthetic enhancement of the campus grounds is the result of the added lighting quality. Since we have a very beautiful campus, we are delighted with this result. It is particularly noticeable when you enter our main campus entrance.

"Finally, and perhaps most important, is the added safety these lights provide for our commuter students attending our Evening Division classes. These students become pedestrians in our parking lot as they move from auto to classroom and back. Since we are rural, one has to be concerned for the personal safety of those who must travel on foot in an area where constant surveillance by security personnel is not possible. We feel we have, with the new lighting system, provided the maximum benefit possible for our foot traffic. Comments from some commuter students indicate that the added protection is real and appreciated."

PUTTING IT ALL TOGETHER: A CALCULATION EXAMPLE

This calculation example has been developed to illustrate a basic method for computing the values of various LEMOs prior to their application. The situation is hypothetical, but nonetheless represents some of the typical modifications that can be made to reduce lighting energy consumption and cost while, at the same time, improving the system and the benefits it provides.

The example involves a 20,000-square-foot self-contained lecture hall 160 feet long and 125 feet wide.

Illumination (100 fc uniform) is provided by a system comprising 182 luminaires (Figure 15), each housing four eight-foot 75W slimline fluorescent lamps. The fixtures are approximately 15 years old and ballasts are ready for replacement. New lamps are installed only when existing ones burn out (spot relamping).

The existing control system consists of circuit breakers only. As such, lighting is either all on or all off. The system is used an average of eight hours per day, six days per week, year-round. It is also used an addi-

tional four hours per week for maintenance crews.

The college is paying \$0.06/kWh for electricity, averaged to include demand.

Although the following LEMOs are discussed in sequential order, all typically would be implemented at the same time. The cost factors indicated are purely speculative and provided for illustrative purposes only. Actual costs will in any case vary from facility to facility.

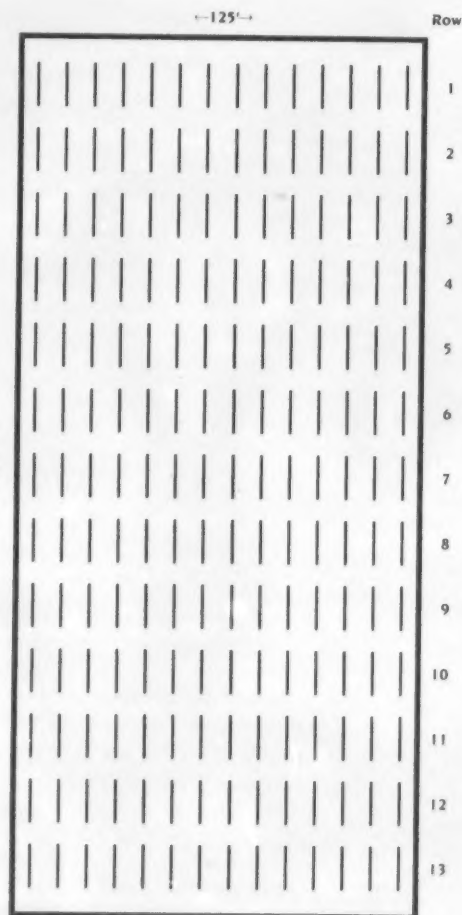


Figure 15: Initial Lecture Hall Layout

EXISTING COSTS

Energy

The annual energy cost of the existing system is derived as follows:

$$\begin{aligned} &75\text{W/lamp} \times 4 \text{ lamps/fixture} \times 1.1 \\ & \quad (\text{ballast loss factor}) \times 182 \\ & \quad \text{fixtures} = 60,060\text{W} = 60.06\text{kW} \\ & \quad \text{connected load} \\ &60.06\text{kW} \times ((8 \text{ hrs/day} \times 6 \text{ days/wk} \times \\ & \quad 52 \text{ wks/yr}) + (4 \text{ hrs/wk} \times 52 \\ & \quad \text{wks/yr})) = 162,402 \text{ kWh/yr} \\ &162,402 \text{ kWh/yr} \times \\ & \quad \$0.06/\text{kWh} = \$9,744/\text{yr} \end{aligned}$$

Replacement Lamps

The lamps are used a total of 2,704 hrs/yr and last an average of 12,000 hours each. For purposes of calculation, they will be changed 0.225 times per year, derived as follows:

$$2,704 \text{ hrs/yr} \div 12,000 \text{ hrs/lamp} = 0.225 \text{ lamp/yr}$$

At an assumed cost of \$3.00/lamp, the cost allocated for new lamps each year is:

$$\begin{aligned} &4 \text{ lamps/fixture} \times 182 \text{ fixtures} \times \\ & \quad 0.225 \text{ lamp/yr} \times \$3.00/\text{lamp} = \\ & \quad \$491/\text{yr for replacement lamps} \end{aligned}$$

Lamp Replacement Labor

Because lamps are replaced on a spot relamping basis, it takes maintenance personnel approximately 30 minutes (0.5 hrs) to change each one (and clean the fixture), due to the time required to fetch lamps from inventory, transport lamp changing equipment, and so on. At a cost of \$7.50/hr (including the cost of fringe benefits), the cost of changing lamps each is:

$$728 \text{ lamps} \times 0.225 \text{ lamp/yr} \times 0.5 \text{ hrs/lamp} \times \$7.50/\text{hr} = \$614/\text{yr}$$

Ballast Replacement

Existing ballasts are due for replacement. At an assumed cost of \$35 per ballast (\$70 per fixture) for labor and materials, the total cost amounts to \$12,740. The new ballasts will last approximately 15 years and then will have to be replaced again. The annualized cost of this future expense, not accounting for inflation, is \$849 per year (\$12,740 $\div$ 15 yrs = \$849/yr).

Existing Cost Summary

The annual cost of operating and maintaining the system each year is:

Energy	\$ 9,744/yr
Replacement lamps	491/yr
Lamp replacement labor	614/yr
Ballast replacement	849/yr
TOTAL	\$11,698/yr

IMPLEMENTING LOAD REDUCTION LEMOs

The initial goal is to reduce the connected load of the lighting system. Several steps are taken, as follows.

Replace Lenses

It is decided to replace existing lenses with those which distribute light more effectively, thus increasing the CU of existing fixtures from 0.60 to 0.70. As a result of this change, the number of fixtures required is reduced to 156.

Paint Ceiling and Provide More Effective Maintenance

In order to derive more light from the existing system, it is decided to paint the ceiling white and implement a high quality, planned maintenance routine.

The new maintenance routine includes annual cleaning of lamps and fixtures, group relamping, and early replacement of lamps (at 70% of rated life).

Given the dingy ceiling which formerly existed and the lack of quality maintenance, it is determined that the improvements will permit a power requirements reduction of some 20%. However, due to other changes planned (see below), it is decided to take a 15% reduction. As such, the number of fixtures is reduced to 132, in 11 rows of 12 fixtures each (Figure 16). As a result, *energy consumption and cost* become:

$$\begin{aligned} &75\text{W/lamp} \times 4 \text{ lamps/fixture} \times 1.1 \\ & \quad (\text{ballast loss factor}) \times 132 \text{ fixtures} \\ & \quad \times 2,704 \text{ hrs/yr} = 117,786 \text{ kWh/yr} \\ &117,786 \text{ kWh/yr} \times \\ & \quad \$0.06/\text{kWh} = \$7,067/\text{yr} \end{aligned}$$

Because lamps will be replaced at the end of 8,400 hours (12,000 hrs $\times$ 70% = 8,400 hrs), each lamp will be replaced, for purposes of calculation, 0.322 time /yr.

$$\begin{aligned} &2,704 \text{ hrs/yr} \div 8,400 \\ & \quad \text{hrs/lamp} = 0.322 \text{ lamp/yr} \end{aligned}$$

As such, the cost of replacement lamps becomes:

$$\begin{aligned} &132 \text{ fixtures} \times 4 \text{ lamps/fixture} \times \\ & \quad 0.322 \text{ lamp/yr} \times \$3/\text{lamp} = \$510/\text{yr} \end{aligned}$$

Group relamping greatly reduces the time required to replace lamps. Because all lamps, equipment and personnel are assembled for the purpose, it will take an estimated 3 minutes (0.05 hrs) to change each lamp and to clean the interior surfaces of the fixture. Thus, the cost of lamp replacement labor becomes:

$$\begin{aligned} &132 \text{ fixtures} \times 4 \text{ lamps/fixture} \times \\ & \quad 0.322 \text{ lamp/yr} \times 0.05 \text{ hrs/lamp} \times \\ & \quad \$7.50/\text{hr} = \$64/\text{yr} \end{aligned}$$

It is decided also to clean the interior surfaces of fixtures approximately once per year, except, of course, during those years in which relamping (and fixture cleaning) occur. As such, fixtures are cleaned 0.643 times per year over each 8,400-hour cycle:

$$\begin{aligned} &8,400 \text{ hrs/lamp} \div 2,704 \text{ hrs/yr} = 3.11 \\ & \quad \text{yrs/lamp} \\ &2 \text{ cleanings/fixture} \div 3.11 \\ & \quad \text{yrs/lamp} = 0.643 \text{ additional} \\ & \quad \text{cleanings/yr} \end{aligned}$$

Assuming that it takes three minutes to clean each fixture, the cost of additional fixture cleaning becomes:

$$\begin{aligned} &132 \text{ fixtures} \times 0.643 \text{ additional} \\ & \quad \text{cleaning/yr} \times 0.05 \text{ hr/cleaning} \times \\ & \quad \$7.50/\text{hr} = \$32/\text{yr} \end{aligned}$$

Install More Efficient Lamps

As another step toward reducing connected load, it is decided to rely on reduced-wattage high-efficiency slimline lamps which require 60W per lamp rather than the 75W of their conventional counterparts. These lamps produce slightly less light than the 75W versions. The light output lost is more than made up by the additional light derived as a result of the newly painted ceiling and better maintenance. (Recall that a 20% lighting reduction was warranted due to painting and maintenance improvements, but only a 15% reduction was made.)

As a result of the new lamps, energy costs fall to \$5.654/yr, derived as follows:

$$\begin{aligned} &132 \text{ fixtures} \times 4 \text{ lamps/fixture} \times \\ &60\text{W/lamp} \times 1.1 \text{ (ballast loss} \\ &\text{factor)} = 34.85 \text{ kW lighting load} \\ &34.85 \text{ kW} \times 2,704 \text{ hrs/yr} \times \\ &\$0.06/\text{kWh} = \$5,654/\text{yr} \end{aligned}$$

The new lamps may be slightly more expensive than their conventional counterparts. Thus, at an assumed rate of \$3.35/lamp, annual replacement lamp cost becomes:

$$\begin{aligned} &528 \text{ lamps} \times 0.322 \text{ lamp/yr} \times \\ &\$3.35/\text{lamp} = \$570/\text{yr} \end{aligned}$$

Install More Efficient Ballasts

It is also decided to reballast the fixtures with new, energy-efficient fluorescent ballasts. Because the existing ballasts must be replaced in any event, the cost of the new ballasts is limited solely to the premium paid for high quality: an assumed \$10/ballast. Based on guidance obtained from the ballast manufacturer, it is determined that the actual power requirement of each fixture with the new ballasts and lamps installed is 250W (down almost 25 percent from the original 330W/fixture). As such, energy consumption and cost become:

$$\begin{aligned} &132 \text{ fixtures} \times 250\text{W/fixture} \times 2,704 \\ &\text{hrs/yr} = 89,232 \text{ kWh/yr} \\ &89,232 \text{ kWh/yr} \times \\ &\$0.06/\text{kWh} = \$5,354/\text{yr} \end{aligned}$$

It must be recognized that the new ballasts provide another benefit: they last from two to three times longer than conventional ballasts. As such, the annualized cost (in today's dollars) of future reballasting (assuming a 37.5-year useful life for the new ballasts) becomes \$317:

$$\begin{aligned} &2 \text{ ballasts/fixture} \times 132 \text{ fixtures} \times \\ &\$45/\text{ballast} = \$11,880 \\ &\$11,880 \div 37.5 \text{ yrs} = \$317/\text{yr} \end{aligned}$$

Load Reduction LEMO Summary

As a result of the LEMOs implemented thus far to reduce the lighting load, revised

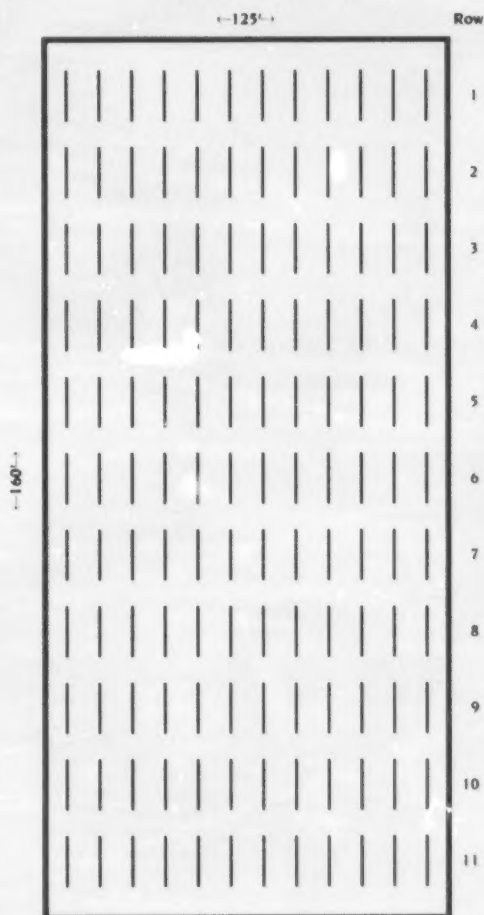


Figure 16: Revised Lecture Hall Layout

annual cost estimates have become:

Energy	\$5,354/yr
Replacement lamps	570/yr
Lamp replacement labor	64/yr
Additional fixture cleaning labor	32/yr
Ballast replacement	317/yr
TOTAL	\$6,337/yr

IMPLEMENTING USAGE REDUCTION LEMOs

Although the lighting load has been reduced from 60.06 kW to 33 kW, (a 27.06 kW, 45% savings), it is realized that more than kW must be looked at.

Install New Switching; Implement Usage Schedules

Based on surveys, it is shown that the lecture hall is near fully occupied only 40% of the time. During other times it is either half- or less-than-half occupied. Accordingly, new switching is installed with two AC snap switches for each row of 12 fixtures. One of the two switches controls the outboard lamps of each fixture; the other controls the inboard lamps. During those normal usage periods when the hall is half- or less-than-half-occupied, lighting in rows 7, 9, and 11 is kept off altogether, and only the outboard (even-numbered days) or inboard (odd-numbered days) lamps of rows 8 and 10 are left on.

It is also recognized that the first row of lighting, used primarily for the lecturer, provides far more light than is needed. Accordingly, a new track light installation is installed, with eight individually controlled "can" fixtures each housing a 120W ellipsoidal reflector lamp. Row 1 fluorescent lighting is thus kept deactivated 90% of the normally-occupied hours. The new incandescent lighting is used 90% of the time, both for general illumination and for purposes of highlighting, to improve student attention span and achievement.

It also is realized that cleaning crews can make better use of lighting. In fact, there is no reason to have all lighting activated four hours per week. Instead, only half of the lighting in even-numbered rows of fluorescent fixtures would be on for the four-hour period.

Given the new usage schedule, annual lighting energy consumption becomes:

Incandescent track lighting

$$0.96 \text{ kW} \times 2,246 \text{ hrs/yr} = 2,156 \text{ kWh/yr}$$

Fluorescent lighting (normally occupied hours; 3 kW/row)

Row 1:	3 kW x 250 hrs/yr =	750 kWh/yr
Row 2:	3 kW x 2,496 hrs/yr =	7,488 kWh/yr
Row 3:	3 kW x 2,496 hrs/yr =	7,488 kWh/yr
Row 4:	3 kW x 2,496 hrs/yr =	7,488 kWh/yr
Row 5:	3 kW x 2,496 hrs/yr =	7,488 kWh/yr
Row 6:	3 kW x 2,496 hrs/yr =	7,488 kWh/yr
Row 7:	3 kW x 998 hrs/yr =	2,994 kWh/yr
Row 8:	3 kW x 998 hrs/yr =	2,994 kWh/yr
	1.5 kW x 1,498 hrs/yr =	2,247 kWh/yr
Row 9:	3 kW x 998 hrs/yr =	2,994 kWh/yr
Row 10:	3 kW x 998 hrs/yr =	2,994 kWh/yr
	1.5 kW x 1,498 hrs/yr =	2,247 kWh/yr
Row 11:	3 kW x 998 hrs/yr =	2,994 kWh/yr

Fluorescent lighting (clean-up period)

$$7.5 \text{ kW} \times 208 \text{ hrs/yr} = 1,560 \text{ kWh/yr}$$

TOTAL ENERGY CONSUMPTION 61,370 kWh/yr

The new annual energy consumption projection represents a 101,032 kWh, 62% savings worth \$6,062/yr.

The revised usage schedules also require recomputation of group relamping schedules and attendant costs.

The incandescent lighting will be replaced 1.25 times per year. At an assumed cost of \$3/lamp, *annual lamp replacement cost* will amount to \$30. The *cost of group relamping labor*, will be \$4/yr:

$$\begin{aligned} 8 \text{ lamps} \times 1.25 \text{ lamps/yr} \times \\ 0.05 \text{ hrs/lamp} \times \$7.50/\text{hr} &= \$4/\text{yr} \\ \$7.50/\text{hr} &= \$4/\text{yr} \end{aligned}$$

Lighting in rows 2, 3, 4, 5, 6, 8 and 10 will be used approximately 2,600 hours per year and so will be relamped 0.310 times per year. The *cost of replacement lamps* will be:

$$84 \text{ fixtures} \times 4 \text{ lamps/fixture} \times 0.310 \text{ lamp/yr} \times \$3.35/\text{lamp} = \$349/\text{yr}$$

The *cost of group relamping labor* will be:

$$336 \text{ lamps} \times 0.310 \text{ lamp/yr} \times 0.05 \text{ hr/lamp} \times \$7.50/\text{hr} = \$39/\text{yr}$$

The *cost of additional fixture cleaning* (0.619 times per year) will be:

$$\begin{aligned} 84 \text{ fixtures} \times 0.619 \text{ additional cleaning/yr} \times 0.05 \text{ hr/fixture} \times \\ \$7.50/\text{hr} &= \$20/\text{yr} \end{aligned}$$

Lighting in rows 1, 7, 9 and 11 will be used approximately 1,100 hours per year (this average used to simplify group relamping scheduling). As such, fixtures will be relamped 0.131 times per year. The *annual cost of replacement lamps* will be:

$$48 \text{ fixtures} \times 4 \text{ lamps/fixture} \times 0.131 \text{ lamps/yr} \times \$3.35/\text{lamp} = \$84/\text{yr}$$

The *cost of group relamping labor* will be:

$$192 \text{ lamps} \times 0.131 \text{ lamps/yr} \times 0.05 \text{ hrs/lamp} \times \$7.50/\text{hr} = \$9/\text{yr}$$

The *cost of additional fixture cleaning* (0.785 times per year) will be:

$$48 \text{ fixtures} \times 0.785 \text{ times/yr} \times 0.05 \text{ hrs/fixture} \times \$7.50/\text{hr} = \$14/\text{yr}$$

NEW ANNUAL COSTS

The new annual cost totals become:

Energy	\$3,682/yr
Replacement lamps	463/yr
Lamp replacement labor	52/yr
Additional fixture cleaning labor	34/yr
Ballast replacement	317/yr
TOTAL	\$4,548/yr

A summary of everything involved in this example is shown in Table 3. Note, again, that this is a hypothetical installation and that the dollar figures are not meant to be representative of actual prices. It should also be recognized that certain LEMOs discussed elsewhere in this booklet have not been utilized, although they very easily could have been. As examples, assuming windows are in place, photocells could have been employed. Photocell/dimmer combinations capable of adjusting for lamp lumen depreciation also would have been effective. Such controls also could have been integrated into a ballast load switching system or, alternatively, a microprocessor-based centralized control system could have been used.

It is important to note that, while hypothetical, the installation described is probably not too different from many existing right now. The dramatic 61% cost reduction was achieved at the same time that the system was actually made more functional, and thus more supportive of the goals of education.

Table 3: Comparison of Existing System vs. Modified Version of Same System

Capital Expense	Existing System	Modified System
Rewire 132 fixtures for split ballasting (when installing new ballasts); install 24 new AC snap switches and circuiting (labor and materials)		\$ 5,300
Premium paid for new ballasts		2,640
528 new lamps (less amount of depreciation attributable to those they replaced) (labor and materials)		1,200
Install 132 new lenses (labor and materials)		2,640
Paint ceiling (labor and materials)		2,800
Remove 50 fixtures and relocate 132 fixtures (labor and materials)		2,800
Install track lighting track, circuitry, track fixtures, lamps and controls (labor and materials)		<u>1,100</u>
TOTAL		\$ 18,680

Annual Operating Expenses	Existing System	Modified System
Energy consumption	\$ 9,744	\$ 3,682
Replacement lamps (annualized)	491	463
Ballast replacement (labor and materials; annualized)	849	317
Lamp replacement labor (annualized)	614	52
Fixture cleaning (annualized)	<u>0</u>	<u>34</u>
TOTAL	\$ 11,698	\$ 4,548

Summary	Existing System	Modified System
Energy savings		
Energy saved each year		101,032 kWh
Percent savings		62%
Energy cost savings		
Energy costs saved each year		\$ 6,062
Percent savings		62%

Summary Continued	Existing System	Modified System
Maintenance cost savings		
Annual cost savings		\$ 1,138
Percent savings		58%
Total operating cost savings		
Total annual cost savings		\$ 7,150
Percent annual cost savings		61%
Simple payback		2.6 yrs
Simple return on investment (ROI)		38%/yr
20-year Projections (Not Accounting for Inflation)		
Capital expense	\$ 00	\$ 18,680
Operating expense	233,960	90,960
TOTAL	\$233,960	\$109,640
20-year Projections (Annual General Inflation 8%; Energy Inflation 10%)		
	Existing System	Modified System
Capital expense	\$ 00	\$ 18,680
Operating expense	647,506	250,516
TOTAL	\$647,506	\$269,196

CASE HISTORY

The South Campus Parking Garage is an 882-space, three-level parking facility serving the South Campus parking needs at the University of Washington in Seattle, Washington. Parking in this facility serves primarily faculty, staff, visitors and patients utilizing the University Hospital and Warren G. Magnuson Health Sciences Center.

The garage facility was built in 1969. After ten years, the garage's fluorescent fixtures showed signs of serious deterioration as a result of rain water dripping between levels and causing corrosion to the metal housings. To stop this condition and also to provide better security and lighting efficiency, the following was accomplished:

1. 696 deteriorated fluorescent light fixtures were replaced with

386 enclosed, weather-resistant, vandal-proof, high pressure sodium luminaires at a cost of \$104,000.

2. Circuitry was redesigned to permit automatic or manual de-energization of fixtures not necessary during daylight hours.
3. The power consumption for garage lighting was reduced from 77 kW to 23 kW.
4. Lighting levels throughout the garage area were increased from 1.5 footcandles to an average of 5 footcandles.
5. Maintenance requirements and costs were reduced by increasing lamp life expectancy from 9,000 hours to 24,000 hours.

Prior to these changes, there were numerous complaints from employees about poor lighting in the second and third levels of the garage. (The hospital's 1,500 employees work a variable shift and return to their vehicles at all hours of the night. They did not wish to park in the garage because of the inadequate illumination.) Administrators of the Hospital and Health Science Center were contacting the Parking Division once or twice each week to relay concerns of persons who were afraid to walk through the garage late at night.

The relighting program has completely eliminated the prior problems. As a result, administrators are now able to spend more of their time and energy on other services and activities in the Hospital and Health Science areas.

SOURCES OF ASSISTANCE

An abundance of literature is available about lighting and lighting energy conservation and management, especially in the form of magazine articles that appear in various publications.

The *Illuminating Engineering Society of North America* (IES) publishes the *IES Lighting Handbook* and other documents. Some of these are technical and geared for engineering personnel; others are suitable for lay audiences. The IES is located at 345 East 47th Street, New York, New York 10017.

The *National Electrical Contractors Association* (NECA) produces a series of periodical monographs called the *Electrical Design Library* (EDL), many of which concentrate on lighting issues. The EDLs usually are available without charge through local NECA chapter offices or member electrical contractors.

The *National Lighting Bureau* (NLB) has several other publications that will be of interest. These include: *Getting the Most from Your Lighting Dollar*, *The Energy-Saver's Guide to Good Outdoor Lighting*, *Lighting Energy Audit Workbook*, and *Lighting Energy Management in Retailing*,

among others. A directory of NLB publications is available without charge by writing to the National Lighting Bureau, 2101 L Street, N.W., Suite 300, Washington D.C. 20037.

Many manufacturers also have guidebooks available. These can be obtained by contacting a manufacturer's representative.

It is recommended strongly that outside assistance be retained to derive optimal results from a relighting program. The local electrical utility may have an assistance program, or at least will be able to identify other local sources of assistance. The same applies to state energy office personnel or regional personnel of the Department of Energy. In many cases they can recommend literature as well.

Manufacturers' representatives often have comprehensive lighting knowledge that goes far beyond the products they deal with. As a result, they frequently can give comprehensive recommendations. Some also can provide computerized analysis, usually at no cost.

Many electrical distributors can also provide product information and computerized technical assistance. Some can

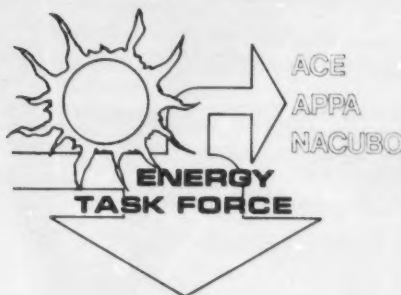
even provide complete fixture conversion programs. For more information, contact a local electrical distributor or the *National Association of Electrical Distributors* (NAED), 600 Summer Street, Stamford, Connecticut 06901. Among its other activities, the NAED routinely published articles and conducts seminars and workshops on lighting.

Many electrical contractors have extensive inspection and design capabilities. For more information about electrical contractors, contact a local chapter office of the National Electrical Contractors Association. Details about lighting system maintenance can be obtained from the *International Association of Lighting Maintenance Contractors*, 2017 Walnut Street, Philadelphia, Pennsylvania 19103.

Engineers who specialize in illumination may be found through a local chapter (section) of the *Illuminating Engineering Society of North America* (IES) or through IES headquarters.



NATIONAL LIGHTING BUREAU
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